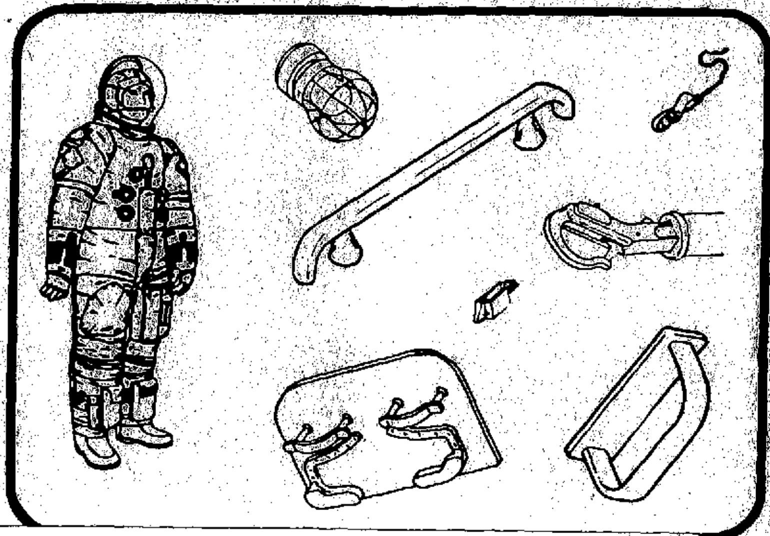

(NASA-CR-141635) DEVELOPMENT OF AN EVA SYSTEMS COST MODEL. VOLUME 2: SHUTTLE ORBITER CREW AND EQUIPMENT TRANSLATION CONCEPTS AND EVA WORKSTATION CONCEPT DEVELOPMENT AND INTEGRATION (URS/Matrix G3/54 N75-17104 Unclas 10217

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VOLUME II

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AND

EVA WORKSTATION CONCEPT DEVELOPMENT AND INTEGRATION

URS MATRIX

FINAL REPORT
JANUARY 1975

URS/MATRIX COMPANY, LIFE & ENVIRONMENTAL SCIENCES DIVISION, SUITE 103, 1275 SPACE PARK DRIVE, HOUSTON, TEXAS 77058

DEVELOPMENT OF AN
EVA SYSTEMS COST MODEL

FINAL REPORT
CONTRACT NAS 9-13790

VOLUME II

SHUTTLE ORBITER CREW AND EQUIPMENT TRANSLATION CONCEPTS

AND

EVA WORKSTATION CONCEPT DEVELOPMENT AND INTEGRATION

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS 77058

URS CORPORATION
URS/MATRIX COMPANY
LIFE AND ENVIRONMENTAL SCIENCES DIVISION
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FOREWORD

The analyses and conceptual designs presented in this report, "Shuttle Orbiter Crew and Equipment Translation Concepts and EVA Workstation Concept Development and Integration," were developed as part of NASA Study Contract No. NAS 9-13790 entitled "Development of an EVA Systems Cost Model." The primary objective of the total study was to provide extravehicular data to assist mission, experiment and payload planners and designers in quantifying the cost of EVA to future vehicles and payloads. This report provides conceptual approaches to EVA support equipment designs and equipment attachment to various Orbiter and payload interfaces.

The work was administered under the technical direction of Mr. David C. Schultz of the EVA and Experiments Branch, Crew Procedures Division, Flight Operations Directorate of the Lyndon B. Johnson Space Center, Houston, Texas.

The total contract report consists of the following three volumes:

Volume I: Design Guides Synopsis--EVA Equipment

Volume II: Shuttle Orbiter Crew and Equipment Translation Concepts and EVA Workstation Concept Development and Integration

Volume III: EVA Systems "Cost" Model

This report (Volume II) is subdivided into the following two areas: (1) developed EVA crewman/equipment translation concepts for Shuttle Orbiter/Payload application; and (2) further developed EVA workstation concepts to meet Orbiter and Payload requirements and integration of workstations into candidate Orbiter/Payload worksites.

PREFACE

The Space Shuttle Program, scheduled to begin Orbiter test flights in the late 1970's, will afford the opportunity to perform a variety of tasks outside the spacecraft. Current plans specify an EVA capability to be provided on both the Shuttle orbital test flights and throughout the operational Shuttle era. Based on the Skylab missions, it is anticipated that each future space program will provide numerous EVA functions and, almost certainly, contingency provisions to enhance mission success. Contingency provisions will include mandatory systems and equipment for crewman safety and rescue.

Planners and designers of Shuttle subsystems and payloads must be cognizant of the operational characteristics of EVA support equipment and man/machine interface requirements in order to effectively design to facilitate EVA servicing. Numerous hardware items that reflect characteristics of the extravehicular hardware required on or near the task being performed have been designed for optimum use by crewmen in the space environment.

This report uses an illustrative approach to recommend various equipment concepts for supporting Shuttle EVA and provides conceptual man/system interfaces to be considered for the Space Shuttle Program. Equipment and interfaces were developed to represent the range of potential EVA operations, based on current (late 1974) data, to be conducted during Shuttle Orbiter missions.

The EVA material presented is divided into two major areas: (1) EVA crewman and equipment translation concepts; and (2) EVA workstation concept development and payload integration. The EVA crewman and equipment translation section provides support equipment concepts for EVA crewman/cargo transfer through the payload bay, to berthed payloads, and to the Orbiter exterior. Attachment concepts and integration techniques for interfacing the transfer equipment into the Orbiter and payloads are provided. The EVA workstation concept development and payload integration section provides

further development of EVA workstation concepts (conceptual designs initiated on a previous NASA contract by URS/Matrix) and methods of attaching the workstations to orbital elements.

The EVA translation/transfer support requirements and the workstation conceptual designs are based on analyses of Shuttle Orbiter subsystems and candidate payload requirements through 1990. A systematic study of the Shuttle Orbiter subsystems, located in the payload bay and on the Shuttle exterior, was conducted to define EVA requirements. The payloads analysis involved both the Automated and Sortie Payloads being considered in mid-1974 for subsequent space applications.

ACKNOWLEDGMENTS

The NASA Technical Monitor for this study was Mr. David C. Schultz, Chief, Procedures Branch (CG2), Crew Training and Procedures Division, Flight Operations Directorate, Johnson Space Center, Houston, Texas. Contract monitoring assistance was provided by Mr. John H. Covington and Mr. Raymond G. Zedekar in the Integrated Procedures Section of the Crew Training and Procedures Division. Appreciation is expressed to Dr. Stanley Deutsch, Director, Bioengineering Division, Office of Life Sciences, NASA Headquarters, for his efforts in arranging for the conduct of the study.

Valuable assistance in obtaining EVA, Shuttle Orbiter and payloads information was supplied by personnel within the NASA Johnson Space Center. Special appreciation is due Mr. John H. Covington/CG251, Mr. Robert R. Kain/CG251, Mr. Stewart L. Davis/LO, Mr. Jack C. Heberlig/LP, Mr. Jerry R. Goodman/EK3, Mr. Maurice A. Carson/EC6, Mr. Joseph J. Kosmo/EC9, Mr. Ted H. Skopinski/LP, Mr. Antoine F. Smith/EW6, Mrs. Jeri W. Brown/EW5, and Mr. Louis E. Livingston/EW3.

The contractor Principal Investigator for the study was Mr. Nelson E. Brown, Division Director, Life and Environmental Sciences Division, URS/Matrix Company, URS Corporation. Principal contributors within the URS/Matrix Company were Mr. Billy K. Richard and Mrs. Betty K. Bielat.

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ACRONYMS AND ABBREVIATIONS

ATM	Apollo Telescope Mount
EVA	Extravehicular Activity
FAS	Fixed Airlock Shroud
FMEA	Failure Mode Effects Analysis
IR	Infra-Red
IVA	Intravehicular Activity
JSC	Johnson Space Center
LM	Lunar Module
LST	Large Space Telescope
MMU	Manned Maneuvering Unit
MSFC	Marshall Space Flight Center
MWP	Maneuvering Work Platform
NASA	National Aeronautics and Space Administration
OMS	On-Orbit Maneuvering System
P/L	Payload
PM	Pulse Modulator
PSS	Payload Specialist's Station
RMS	Remote Manipulator System
SIM	Scientific Instrument Module
SSPD	Space Shuttle Payload Descriptions
TPS	Thermal Protection System
UV	Ultraviolet

The Space Shuttle Program will introduce the capability of placing numerous experiment payloads into earth orbit for observation of the earth's surface, conduct of experiments and investigations of the space environment, and research into scientific and technological areas that capitalize on the unique characteristics of the "weightless" environment. The orbital payloads will vary in content, configuration and purpose from self-contained orbital laboratories to automated research satellites, and possibly, to payload modules forming a permanent earth-orbiting space station. The frequent Shuttle missions will present experiment planners and designers with many new and unique payload/experiment support and servicing requirements not encountered on previous space programs. Preliminary analyses have resulted in the identification of Orbiter subsystems and payload experiments that will require operations to be performed by extravehicular activities. This report defines basic EVA support equipment requirements and develops conceptual designs of EVA hardware to provide crewman and cargo access to the required worksites including restraint at the site.

1.1 STUDY SCOPE AND APPROACH

The overall objective of the study, "Development of an EVA Systems Cost Model," was to compile, develop, format and distribute information to assist Shuttle mission planners and system designers in quantifying the cost of EVA to the Orbiter and payloads. The study included four (4) major tasks and several related subtasks to reach the major objectives. The major tasks are listed below:

- Develop crewman and equipment translation/transfer concepts
- Develop EVA workstations and workstation attachment concepts
- Develop a design guides synopsis of EVA equipment from previous space programs
- Develop an EVA systems cost model

The overall study approach and its relationship to previous studies is illustrated in Figure 1.1.

The study results provided in this volume of the final report combine Tasks 1 and 2 of the overall study. The major end product of Task 1 was the development of Shuttle Orbiter EVA support equipment concepts to provide the following EVA capability:

1. Crewman translation through the payload bay and to payload worksites
2. Cargo transfer to payload bay and Orbiter-attached payload worksites
3. Crewman access to the Orbiter exterior

Concepts were also developed for attachment/integration of the crewman translation and cargo transfer equipment into the Orbiter subsystems and payload structures.

Portable EVA workstation conceptual designs were initiated in previous studies and expanded in Task 2 of this study. The Task 2 objectives were to consider modular EVA workstation concepts and to develop workstation attachment concepts including methods/techniques for integrating the workstations into the Orbiter and payload systems. The conceptual designs developed are contained in Sections 5.0 and 6.0 of this report.

Several prerequisite tasks were required prior to initiating EVA supporting equipment conceptual designs:

- Analyze the Shuttle Orbiter payload bay EVA requirements, candidate worksite locations and constraints imposed on EVA by the vehicle
- Analyze candidate payload on-orbit servicing requirements, external configurations, and launch arrangements in the payload bay
- Review EVA support equipment used on previous space programs and crewman comments on Skylab EVA

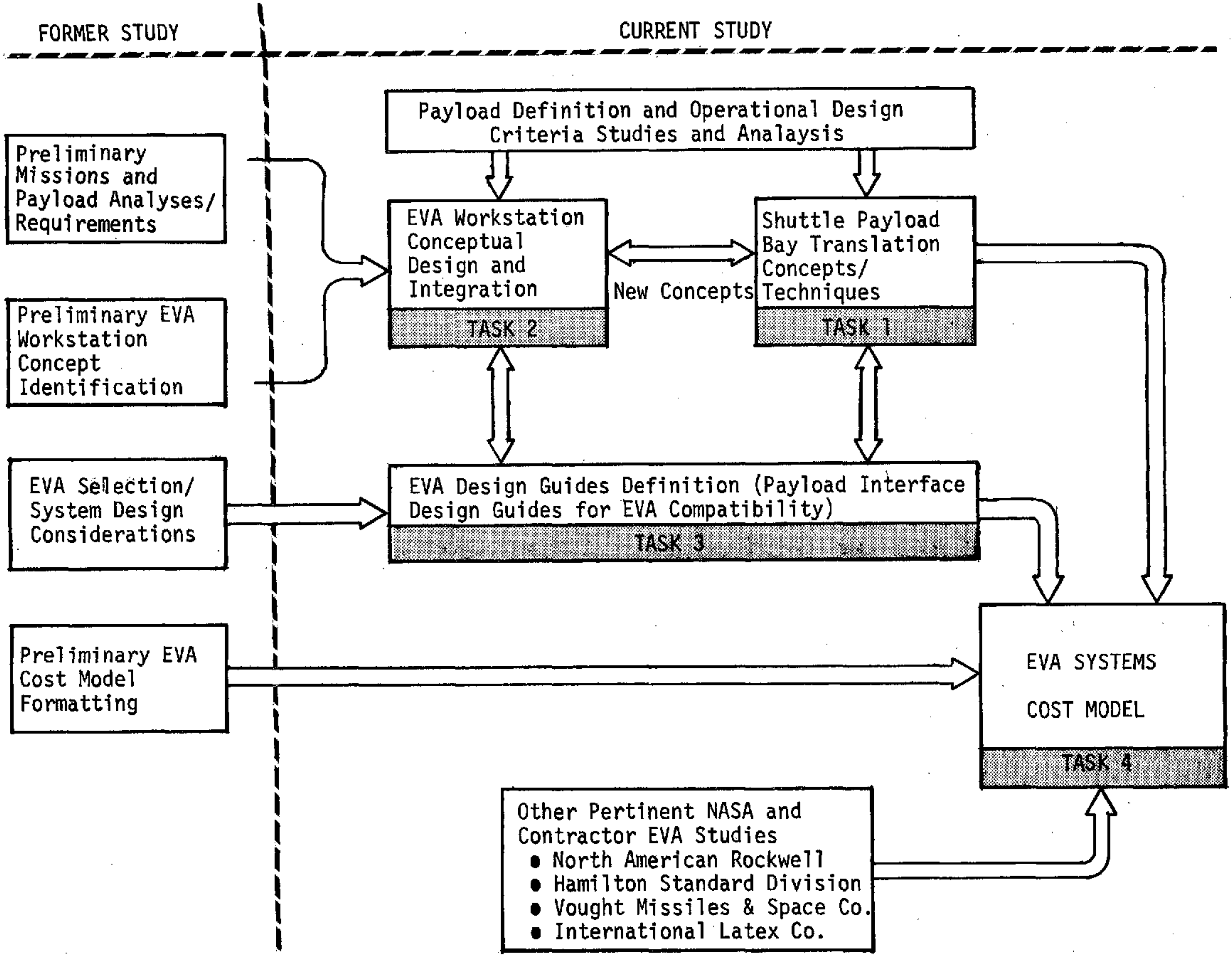


FIGURE 1.1: Study Tasks Interrelationship

- Define operational design criteria of EVA translation/transportation systems to satisfy Orbiter and payload requirements

The results of preparatory studies and the EVA requirements analyses conducted prior to EVA support equipment concept development are contained in Sections 2.0 through 4.0.

1.2 STUDY GUIDELINES AND ASSUMPTIONS

A number of guidelines and assumptions were established for conducting supporting analyses and developing EVA support equipment concepts. Several existing EVA systems and hardware items were assumed adequate to support Shuttle EVA functions including the following:

- Handrails and handholds
- Foot restraints used on Skylab
- Extendible booms (cargo transfer)
- Spacesuits
- Lighting
- Temporary hardware stowage provisions
- Tether hardware technology
- Life support systems technology

The above support hardware applications were considered throughout the study from the economic aspects of new equipment development and off-the-shelf hardware availability. The major guidelines and additional assumptions are listed below.

General Guidelines

- Orbiter capability for conducting EVA (planned or unscheduled) from the cabin airlock, EVA egress module, or side hatch will be provided.
- In the event the payload bay doors cannot be opened, EVA will be from the Orbiter side hatch.
- EVA crewmen and "loose" equipment must be tethered at all times.

- EVAs may be performed during both light and dark periods.
- "Dark side" lighting for translation will be provided by the Orbiter.

Concept Development Guidelines

- Previously qualified EV equipment should be applied, where possible.
- Concepts should be functionally simple to operate to minimize development cost and crew training.
- EVA man-machine interfaces should be standardized, if possible.
- Translation/transfer equipment must be interchangeable for different payload arrangements.
- Translation/restraint system-to-vehicle interfaces should be highly flexible to allow rapid ground and/or in-flight installation and be positive locking.
- Single failure of an EVA system must not injure or incapacitate the EVA crewman, cause vehicle or payload damage, prevent cabin ingress or safe return to earth.
- Installation or maintenance of translation/transfer/restraint equipment should be accomplished on-orbit by hand or, at most, with "ordinary" hand tools.

General Study Assumptions

- Nominal EVA mode will be two-man EVAs; one man-EVAs may be conducted.
- The Shuttle Orbiter will provide crewman translation aids to the major bulkheads and through the payload bay.
- The payloads will provide translation/cargo transfer equipment required for payload support.
- Pressure suits, if developed for the Shuttle Program, will be at least as mobile as Skylab suits.

- Life support systems will not increase or decrease appreciably in size and weight over Skylab systems.
- Portable life support systems will be the primary system for Shuttle use.
- EVA routes will be free of hazardous protrusions, sharp edges and corners of Orbiter/payloads equipment which can be easily damaged.
- Electrical power will be available for EVA support equipment use (i.e., for lights, cameras, power tools).
- The Remote Manipulator System (RMS) may be used for cargo transfer and crewman translation path (handrails).
- Free-flying maneuvering units may be used for inspection/repair of the Orbiter exterior and free-flying satellites.

The sections to follow describe the methodology employed and findings of each subtask of the EVA support equipment conceptual design effort.

SECTION 2.0 SHUTTLE EVA APPLICATIONS/REQUIREMENTS ANALYSES

A comprehensive review and analysis of NASA and contractor Shuttle documentation were conducted to identify the requirements and determine the necessary characteristics of EVA crewman translation, cargo transfer and work-site provisions to support the Shuttle Program. Numerous potential, candidate and planned EVA applications were identified. A summary of the analyses and applications is provided.

2.1 SHUTTLE ORBITER EVA APPLICATIONS ANALYSIS

2.1.1 Orbiter Payload Bay

The Orbiter payload bay subsystems/equipment reviewed for candidate EVA on-orbit servicing applications and the interfaces considered for EVA support hardware attachment are listed below:

- Payload bay subsystems/equipment
  - Payload bay doors (closing mechanisms, linkages, latches, drive units, etc.)
  - Radiators and radiator deployment mechanisms
  - Payload retention mechanisms
  - Electrical power/pneumatic system components
  - Environmental control and life support subsystem/components
  - Orbiter payload bay liner
  - Remote Manipulator System (RMS)
  - Lighting
  - Payload bay liner and attachments
- Orbiter EVA equipment interfaces considered
  - Forward (Sta. 576) and aft (Sta. 1307) bulkheads
  - Payload bay longerons
  - Primary payload support frames
  - Payload stub frames
  - Payload bay doors (interior surfaces)

Detailed design of Orbiter subsystem components, their locations and integration into the payload bay were in a fluid status during the EVA applications analysis (late 1974). The subsystems are not currently designing for on-orbit EVA access or equipment servicing, and only a limited number appear to be at a sufficient design level to identify potential EVA requirements. Failure mode effects analyses (FMEAs) on most Orbiter subsystem design concepts have only been scheduled, few initiated. The Orbiter payload bay door subsystem designers have, however, recognized a requirement to access the door closing mechanisms as a backup to the electro-mechanical systems.

Since it appears relatively early in the Orbiter payload bay subsystems development and qualification programs to specify EVA requirements, the EVA crewman translation aids and cargo transportation system conceptual designs presented in subsequent sections allow access to all payload bay areas. The Orbiter payload bay equipment/structures proposed (by the study) for attachment of the EVA support hardware (conceptual) included the payload bay doors, forward and aft bulkheads, and primary payload support frames.

2.1.2 Orbiter Exterior Subsystems

The major Orbiter external subsystems and equipment reviewed for candidate EVA applications are listed below:

- Thermal Protection System (TPS)
- On-orbit Maneuvering System (OMS)
- Orbiter main engines
- Control surfaces
- Payload bay doors
- Landing gear and doors
- Reaction control system doors
- Star tracker and door
- Radiators and deployment mechanism
- Orbiter vent doors
- External tank doors
- Launch umbilical doors
- Windows
- Orbiter side hatch

The Thermal Protection System (TPS) external doors subsystem designers are studying contingency access requirements for on-orbit systems repair. Most external subsystems are not currently (late 1974) into the design phase

to determine EVA requirements based on failure probabilities. Although repair of the TPS appears a strong contingency application, information on the TPS and other external subsystems relative to EVA is not expected until FMEA studies are complete. Several of the subsystems studied are not accessible on-orbit due to the extensive thermal protection requirements for reentry and the TPS design characteristics.

For concept development, two systems are being considered for EVA access to the Orbiter exterior--the manned maneuvering units being proposed and the baselined remote manipulator system. The Orbiter exterior equipment proposed for attachment of EVA support hardware include the thermal protection system, external doors (i.e., internal structural members accessible when open), and removable external panels.

2.2 PAYLOADS EVA APPLICATIONS ANALYSIS

2.2.1 Sortie/Spacelabs Payloads

Analyses of the NASA-MSFC Space Shuttle Payload Descriptions (SSPD) documents, payload planning working group reports and specific payload-related documentation were conducted relative to Shuttle EVA applications and requirements. The October 1973 Sortie SSPD documents identified 61 payloads, 7 of which specified planned EVA and 13 contingency EVA requirements. (The EVA requirements breakout is based on the URS/Matrix analysis.) The June 1974 update of the SSPD identified 96 payloads with 7 acknowledging planned EVA and 54 contingency requirements. Each EVA requirement was specified in the documents referenced above; no EVA requirements predictions were made by the contractor. However, each payload was analyzed relative to potential EVA applications from a contingency, enhance-the-mission-success approach. Since an EVA capability will be provided on both the Shuttle orbital test flights and all operational flights, elimination of contingency EVA from any payload becomes more difficult, if not impossible, to justify.

Based on mid-1974 Sortie Payloads data, the EVA applications/requirements status is depicted in Table 2-1. Several EVA requirements analyses have been conducted by other aerospace contractors, including Rockwell International and the Essex Corporation. Results of the analyses are shown in the table. Of significance to the EVA and payloads organizations is the significant upward trend in Sortie Payloads specifying contingency EVA requirements.

2.2.2 Automated Payloads

An in-depth review similar to the Sortie Payloads analysis was conducted to identify Automated Payload EVA applications and requirements. Eighty-one payloads listed in the NASA-MSFC Space Shuttle Payload Descriptions (SSPD) documents were reviewed. The October 1973 SSPD document identified 76 Automated Payloads; 4 specified planned EVA while 19 acknowledged a potential requirement for contingency EVA. The July 1974 SSPD issue specified 5 planned and 54 contingency EVA applications from a total of 81 payloads. Several payloads specifying planned EVA also acknowledged contingency EVA in the event of system malfunctions.

The number of Automated Payloads acknowledging contingency EVA increased significantly from the original October 1973 SSPD documents to the July 1974 revisions. As the payloads become better defined and the Shuttle Orbiter payload accommodations relative to EVA are determined, more experimenters appear to be considering EVA as a backup to automated equipment. The current (mid-1974) status of the Automated Payloads relative to EVA requirements is shown in Table 2-2. The July 1974 issue of the Summarized Automated Payload Descriptions document is considered a more authoritative source.

2.3 REPRESENTATIVE SHUTTLE PROGRAM EVA APPLICATIONS

As part of the Orbiter and payloads EVA applications/requirements analyses, a number of candidate EVA tasks were identified. The task descriptions immediately tended to develop a commonality across payloads such as inspect, repair, service, remove, replace, etc. Since man's EVA capabilities and performance

TABLE 2-1: Sortie Payloads EVA Requirements Status

DOCUMENT DATE	SOURCE DOCUMENT	TOTAL PAYLOADS	EVA REQUIREMENT CLASS: PLANNED	PLANNED TBD	CONTINGENCY	NONE	NO REPLY	TOTAL REQUIRING EVA ACCESS
Oct 73	Sortie Payloads Description Document and Summarized Sortie Payloads Description Document--MSFC ( )--Summarized Document	43 (61)	7		13		41	20
May 74	Essex Corporation: Study of the Roles of RMS and EVA for Shuttle Mission Support	34*	5		--			5
June 74	Rockwell International Corporation: List of Sortie Payloads Requiring EVA/IVA On-Orbit Access	--	--	--	--			16
June 74	Sortie Payloads Description Document --MSFC	27	1	2	14	12	1	17
June 74	Summarized Sortie Payloads Description Document--MSFC	96**	7@		54	42		61

* Includes manned EVA and RMS

** Includes 8 revisits and combinations of previous payloads

@ Includes up to 3 EVAs per flight for a total of 15 EVA missions

TABLE 2-2: Automated Payloads EVA Requirements Status

DOCUMENT DATE	SOURCE DOCUMENT	TOTAL PAYLOADS	EVA REQUIREMENT CLASS					TOTAL REQUIRING EVA ACCESS
			PLANNED	PLANNED TBD	CONTINGENCY	NONE	NO REPLY	
Oct 73	Automated P/L Description Document and Summarized Automated P/L Description Document--MSFC ( )--Summarized Document	51 (76)	4		19		28	23
May 74	Essex Corporation: Mid-term Review, Study of the Roles of RMS and EVA for Shuttle Mission Support	51*	12		--			12
June 74	Rockwell International List of Automated Payloads Requiring EVA/IVA On-Orbit Access	--	--		--			25
July 74	Automated P/L Description Document--MSFC	49	1	1	9		36	10
July 74	Summarized Automated P/L Description Document--MSFC	81	5	1	54	16	11	57

*Includes manned EVA and RMS

characteristics are generally known, an attempt to predict all of the possible EVA applications for each potential Orbiter and payload application was not undertaken. Most payloads are not designed or Shuttle-integrated sufficiently to avoid extreme repetition and vague, ambiguous predictions. The EVA support equipment concepts being developed on this contract are based on proven EVA capabilities coupled with general types of EVA tasks derived from the Shuttle payloads and Orbiter subsystems analyses. Specific EVA tasks currently recognized by the payload designers appear to be well within the crewman's capabilities.

A sample listing of general EVA applications derived from the Orbiter and payloads analyses is contained in Table 2-3. The listing is not intended to be inclusive of all potential Shuttle Program EVA tasks but to serve as an indication of the numerous and various applications. The payloads currently planning for EVA support have indicated specific tasks; a representative list is provided in Table 2-4. The EVA support equipment concepts are designed to satisfy not only currently planned EVAs but a wide range of potential applications.

TABLE 2-3: General EVA Tasks Identified From Orbiter and Payload Subsystems Analyses

- Exchange Subsystem Elements
  - Film Magazines/Cameras
  - Equipment Modules/Components
- Repair Subsystems
  - Orbiter TPS
  - External Doors
- Aid Payload Deployment or Jettison From Bay
- Aid Recapture of Payloads
- Prepare Payloads for Earth Return
- Replenish Payload Subsystems
  - Cryogenics
  - Instrument Gas
  - Propellant
- Antenna Feed Change
- Inspect/Checkout Payloads and Their Systems
- Aid Deployment of Payload Mechanical Subsystems
  - Booms
  - Arrays
  - Antennas
- Aid Retraction of Payload Mechanical Subsystems
- Assemble Large Structures in Space (e.g., Antennas, Booms)
- Monitor Experiment Operations
- Astronaut Rescue
- Photographic Support

TABLE 2-4: Representative EVA Tasks Specified By Payloads

PAYLOAD	TASK
• AS-01-A[1], LST	Repair/exchange system elements and/or scientific instruments
• SO-02-A, Large Solar Observatory	Prepare recovered payload for descent
• HE-09-A, Large High Energy Observatory B	Replenish LHe; replace PM tubes, counter detectors, and instrument gas
• AS-09-S[2], 30M IR Interferometer	Aid beam interferometer deployment and retraction
• EAS-01-S, UV-1 (Pastel)	Repair--access to the focal plane, film retrieval on pallet
• SP-01-S, Dedicated Solar Sortie Mission	Contingency--recover film
• OP-01-S, Solid Earth and Ocean Dynamics Test Bed	Contingency--repair or antenna deployment assistance

[1] xx-xx-A indicates an Automated payload

[2] xx-xx-S indicates a Sortie payload

SECTION 3.0 EVA SYSTEMS REVIEW FROM PREVIOUS SPACE PROGRAMS

EVA support equipment used on previous space programs (excluding space-suits and life support systems) and the more innovative concepts, although not flown, were reviewed for Shuttle application. The equipment/systems were analyzed relative to satisfying the planned and potential tasks identified in the analyses, Orbiter and payload impact, crewman man-system interface and integration into the orbital systems.

3.1 CREW AND CARGO TRANSFER EQUIPMENT/TECHNIQUES

A review of EVA crew and cargo transfer equipment used, developed or proposed for previous space programs was conducted to determine the applicability to the Shuttle Program. An abbreviated list is shown in Table 3-1. Many hardware items reviewed were considered totally inadequate while others were considered unnecessary based on current knowledge of crewman capabilities in a weightless environment and EVA crewman comments regarding EVA equipment design, particularly from the Skylab Program. The EVA translation systems used on previous space programs--some with moderate modification--appear most applicable to the Shuttle Program. The Skylab systems included handholds, handrails (single and dual), wrist tethers, clothesline transfer system, and extendible booms. Systems currently under consideration for the Shuttle Program--not from previous programs--that appear highly applicable as EVA crew/cargo transfer aids are the Manned Maneuvering Units (MMUs) and Remote Manipulator Systems (RMS). Modification concepts to several of the above systems for Shuttle application are shown in Section 5.0 of this report.

3.2 EVA WORKSTATION REVIEW

EVA workstations designed for the Gemini, Apollo and Skylab Programs were reviewed. Workstations on the previous programs were fixed, dedicated stations except two foot restraint attachment units devised for specific EVA contingency functions on Skylab. The worksites/workstations reviewed included the following:

TABLE 3-1: Crew and Cargo Transfer Equipment/Techniques Reviewed

- Directional Free Floating
  - Tethered
- Handholds
  - Fixed
  - Portable
- Handrails
  - Single
  - Dual
  - Portable
  - Mobile Handhold (Rail Mounted)
    * Standard Motor-Gear
    * Linear Induction
    * Battery Powered
- Magnetic Shoes
- Astrogrid Shoes
- Clotheslines
- Wrist Tethers
- Waist Tethers
- Tether Reels
- Equipment Tethers
- Dual Rail Platform Trolley Equipment Transfer
- Remote Manipulator System (RMS)
  - Cargo Transfer End Effector
  - Crew Transfer Platform
  - Crew Work Platform (Workstation)
  - Handrails (Segmented) on AMS Structure
- Dual Rail Platform Trolley (Equipment Transfer)
- Powered Conveyor (Chain/Cable Type)
- Self-Powered Trolley Type Devices
  - Hand Operated
  - Foot Operated
- Maneuvering Units (Free-Flying)
  - Hand-Held
  - Manned Maneuvering Unit (MMU)
  - Maneuvering Work Platform (MWP)

- Gemini
  - Spacecraft adapter equipment section worksite
- Apollo
  - Scientific Instrument Module (SIM) worksite
  - Lunar Module (LM) worksite
- Skylab
  - Fixed Airlock Shroud (FAS) workstation
  - Apollo Telescope Mount (ATM) workstations
    * Center workstation
    * Transfer workstation
    * Sun end workstation
    * Sun shade foot restraint (contingency)
    * Experiment S193 foot restraint (contingency)

Analyses of EVA workstations, EVA tasks performed on previous space programs and the Shuttle EVA applications/requirements indicate that a portable, modular, one-man workstation would be the most applicable for the Shuttle Program.

3.3 EVA CREWMAN COMMENTS (SKYLAB)

No problems were encountered with the handholds, handrails and foot restraints on the later Apollo or the Skylab Programs. Crew comments from voice transcripts and crew debriefings were very favorable. The foot restraints were easy to ingress/egress and provided positive restraint for all required movements. The first Skylab crew commented, "The single handrails were a perfectly feasible way to translate, while dual handrails were like driving the interstate highway."

Handholds and handrails have proven their usefulness on past programs and appear to be a reliable and economical approach on the Shuttle Program for both payload bay and payload access.

By integrating the results of the reviews and analyses discussed in Sections 2.0 and 3.0 preliminary crewman translation and cargo transfer system design guidelines/criteria were developed. A corresponding set of guidelines for workstation development and integration is provided.

4.1 CREW/CARGO TRANSFER SYSTEMS

The crew/cargo transfer systems design guidelines and criteria for supporting EVA missions are based on the Orbiter vehicle and payload requirements defined from documentation available to the contractor during the review and analysis phase of the study. The level of detail available on Orbiter payload bay subsystems and payload EVA tasks affects the design criteria for EVA support equipment. The level of detail desired by the contractor was not available during the analyses to permit specifying detailed-operational design criteria. The general EVA support systems design guidelines/criteria described below are based on factors from the Orbiter subsystems and payload analyses conducted during this study and EVA requirements from previous programs. Several of the study guidelines defined early in the study are now considered general design guidelines by the contractor.

- Provide EVA access to all areas of the payload bay and to berthed payloads
- Provide EVA access to the entire Orbiter exterior
- Use single and dual handrails as primary crewman mobility system for payload bay access
- Use standard Apollo handhold and handrail cross-sectional configuration
- Utilize proposed Orbiter and payload structures for EVA equipment attachment
- Provide interchangeable handrails and handholds for various payload arrangements and rapid payload bay reconfiguration

- Powered mobility aids for payload bay or berthed payload access are not required. (The RMS may serve as a mobility aid if attached (i.e., end effector) to the worksite structure.)
- Utilize the Orbiter Remote Manipulator System (RMS), with appropriate EVA equipment addition, for EVA cargo transfer and mobility aid
- Consider RMS/EVA workstation for crewman restraint and attachment to worksite
- Use Manned Maneuvering Unit and RMS for Orbiter exterior access
- Design cargo transport systems for one-man operations
- Standardize EVA man-machine interfaces when within economic/design capability
- Provide functionally simple designs (for EVA glove operation) on all EVA support equipment
- Installation and maintenance of translation/transfer/restraint equipment should be accomplished on-orbit without tools or as worse case, with "ordinary" hand tools

4.2 EVA WORKSTATIONS

Although a variety of inspection, alignment, monitoring, and calibration tasks were specified in the Shuttle documentation, these tasks were not considered major drivers for EVA workstation design. The potential package/module handling tasks, force applications, access requirements and attachment interfaces were considered the critical parameters. As workstation concepts are developed that afford the desired mobility, visibility and flexibility in crewman positioning based on the parameters above, the workstations should afford the desired access for the inspection, alignment, and calibration tasks.

By consolidating the planned and potential EVA tasks identified through the Orbiter and payloads analyses, a generic task listing was derived. At

a top level, the following types of tasks will be required in EVA operations on the Space Shuttle Program:

- Repair
- Deploy
- Handle packages
- Clean
- Remove/replace
- Assemble
- Checkout
- Inspect
- Monitor
- Align
- Adjust
- Calibrate
- Activate/deactivate

Based on the analyses performed during the study and EVA information from previous space programs, the following general EVA workstation design guidelines are listed below. The workstation should:

- Be portable, lightweight and low volume (i.e., may be transported and positioned on-orbit by the EVA crewman or RMS)
- Incorporate support provisions for conducting a variety of Shuttle operations
- Interface with standard Orbiter and payload structural configurations
- Provide crewman and module (stowage) restraint
- Provide crewman ingress/egress aids
- Use Skylab-type handholds and foot restraints
- Provide tool kit attachment interface
- Provide stowage for small replacement items
- Standardize the crewman operational equipment interfaces
- Design for workstation attachment/adjustment with the EVA gloved hand
- Provide additional tool interfaces for all hand-tightened components
- Provide auxiliary worksite lighting attachment provisions

SECTION 5.0 CREW AND EQUIPMENT TRANSFER CONCEPTS

The various payload configurations and equipment mounting provisions accommodated by the Orbiter payload bay may require an EVA crew and equipment translation scheme/system for each "generic" payload bay arrangement. The EVA crewman may be required to access an empty payload bay, a payload bay containing a Spacelab and a high density experiment pallet, an automated payload extending from the payload bay, a five pallet payload arrangement, or any point on the Orbiter exterior. The EVA access requirements throughout the Orbiter payload bay and to berthed payloads indicate that a relatively simple handrail/handhold system would satisfy the majority of EVA missions. No requirements for a power-assisted crewman translation system (e.g., rail-mounted powered trolley/handhold) were identified for payload bay or berthed payload EVA access. The Shuttle Remote Manipulator System (RMS) and Manned Maneuvering Unit (MMU) were defined, by the study, as primary candidates for accessing the Orbiter exterior and free-flying satellites/payloads.

The transportation of cargo within the payload bay and to berthed payloads may be satisfied with systems/techniques such as clothesline systems, crewman "hand-carry," extendible booms, etc. However, since the payload/experiment equipment density may restrict "straight-line" cargo transporting systems, the RMS should be considered for EVA crewman support. No unique Shuttle cargo transfer system requirements were identified for payload bay or berthed payloads, based on mid-1974 Shuttle documentation. Equipment transported to the free-flying satellites, automated payloads and certain external areas may require free-flying maneuvering units.

The following subsections provide tentative translation route layouts, suggested translation and cargo transfer hardware for Shuttle application, conceptual design, and hardware attachment concepts.

5.1 CREW TRANSLATION SYSTEMS

5.1.1 Currently Proposed Payload Bay EVA Access

The current (preliminary) EVA mobility aid quantity, location, and configuration being considered by Rockwell International (Shuttle Orbiter prime contractor) are depicted in Figure 5.1. These mobility aids would be supplied by the Orbiter vehicle for payload bay access. Additional payload or payload bay EVA access provisions would be payload chargeable. The Rockwell proposed (preliminary) concepts consist of the following:

- Handrails running the length of the payload bay doors (both sides)
- Handrails on both the forward and aft bulkheads
- Lifelines (three coated lines .64 cm. (.25 in.) in diameter) through the payload bay

Although several of the EVA mobility aids are referred to as "lifelines," this study (Volume II) recommends several modifications and additions to the proposed concepts based on the following:

A Gemini Program conclusion was that grasping a cylindrical rail .95 cm. (.375 in.) in diameter was fully possible but highly undesirable. Cylindrical objects 1.9 cm. (.75 in.) were evaluated on the same program and were found more appropriate (ref. 1 and 2). An "oval" shaped (cross-section) handrail was developed for EVA translation and was used on all U.S. manned space programs since Gemini. A handrail cross-section of approximately 3.2 x 1.6 cm. (1.25 x .62 in.) and rigidly attached was used on the Skylab Program with optimum results.

From the above evaluation, an objective consideration should be given to grasping a .64 cm. (.25 in.) diameter taut-cable (Rockwell's proposed "lifeline" system) with the EVA glove for translation. A recommended modification

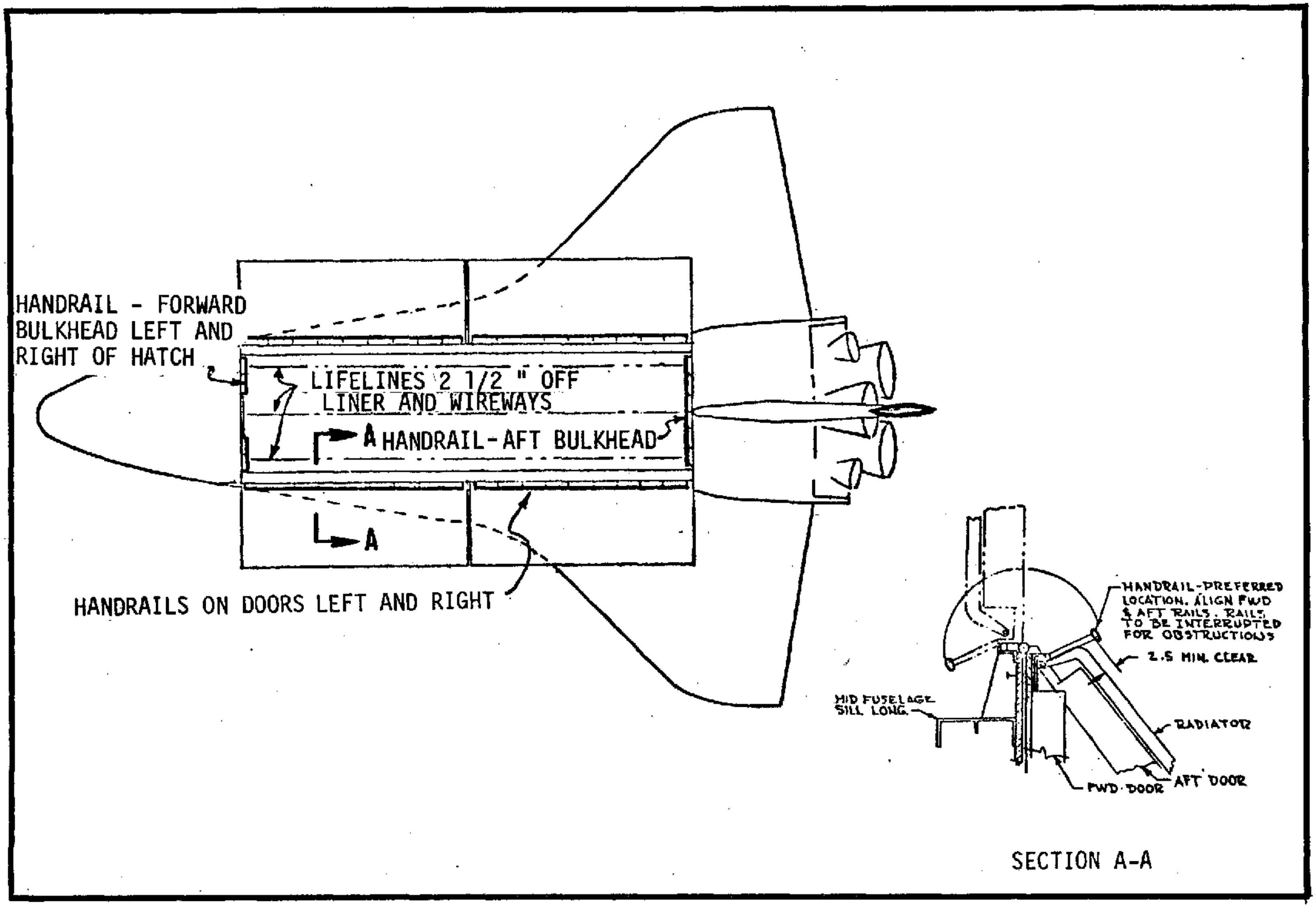


FIGURE 5.1: Proposed (Rockwell International) Payload Bay Handrail/Lifeline System

to this system would be to replace the two outer lifeline cables, running the length of the payload bay, with a rigid handrail system. The center lifeline would remain as a sliding tether attachment (Figure 5.2). The recommended modifications are to provide only the interfaces in the payload bay and install EVA mobility aids, as required.

5.1.2 Orbiter/Payload Bay Constraints on EVA Hardware

Prior to recommending handrail locations/routings and developing attachment concepts, equipment in the payload bay was reviewed relative to constraining the EVA translation equipment installation. Figure 5.3 shows three payload bay structural/protective hardware items of concern in the development of EVA translation concepts. These items affect EVA translation and workstation hardware development and crew capabilities/access as follows:

- Payload Bay Liner
  - If liner covers "Tee" section of primary payload support frames, on-orbit installation of portable mobility aids will be inhibited
  - Ground installation of handrails will require "thru-liner" provisions
  - EVA crewman cannot grasp protrusions, structural hardware, etc. as on previous space programs
- Electrical Wire Tray
  - Approaches crewman maximum reach distance across trays
  - Complicates crewman access (restraint, stabilization and worksite provisions location/attachment) to adjacent payloads
- Primary Payload Support Frames (Main Frames)
  - Various frame spacing prohibits standard handrail sections (spacing varies between 1.3 and 1.5 m. (50 and 60 in.)
    (Tee section provides candidate interface for translation aid and workstation attachment)

Several other Orbiter hardware subsystems impacting EVA equipment "desired" location, quantity, and installation method are listed as follows:

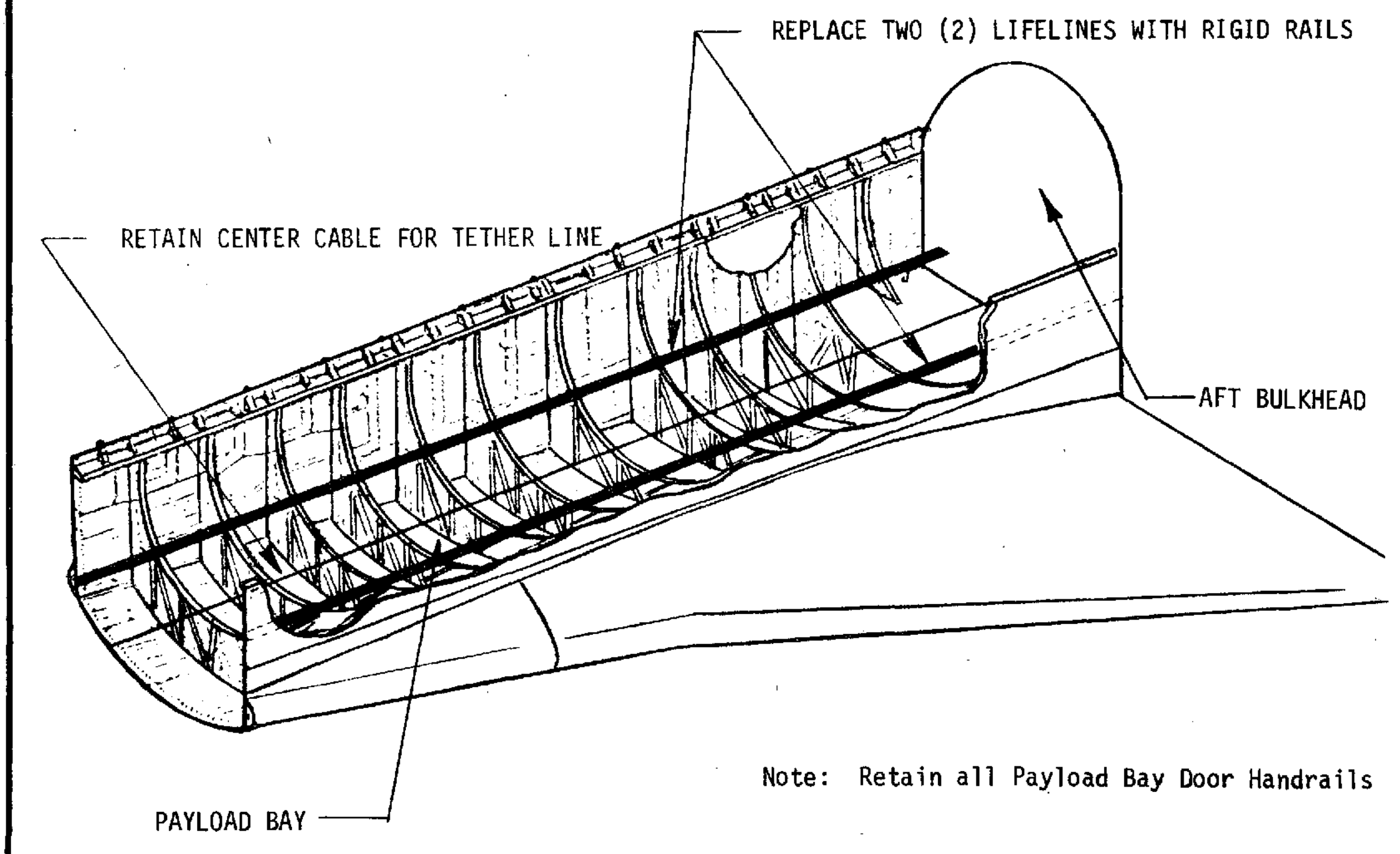


FIGURE 5.2: Suggested Payload Bay "Lifeline" System Modification

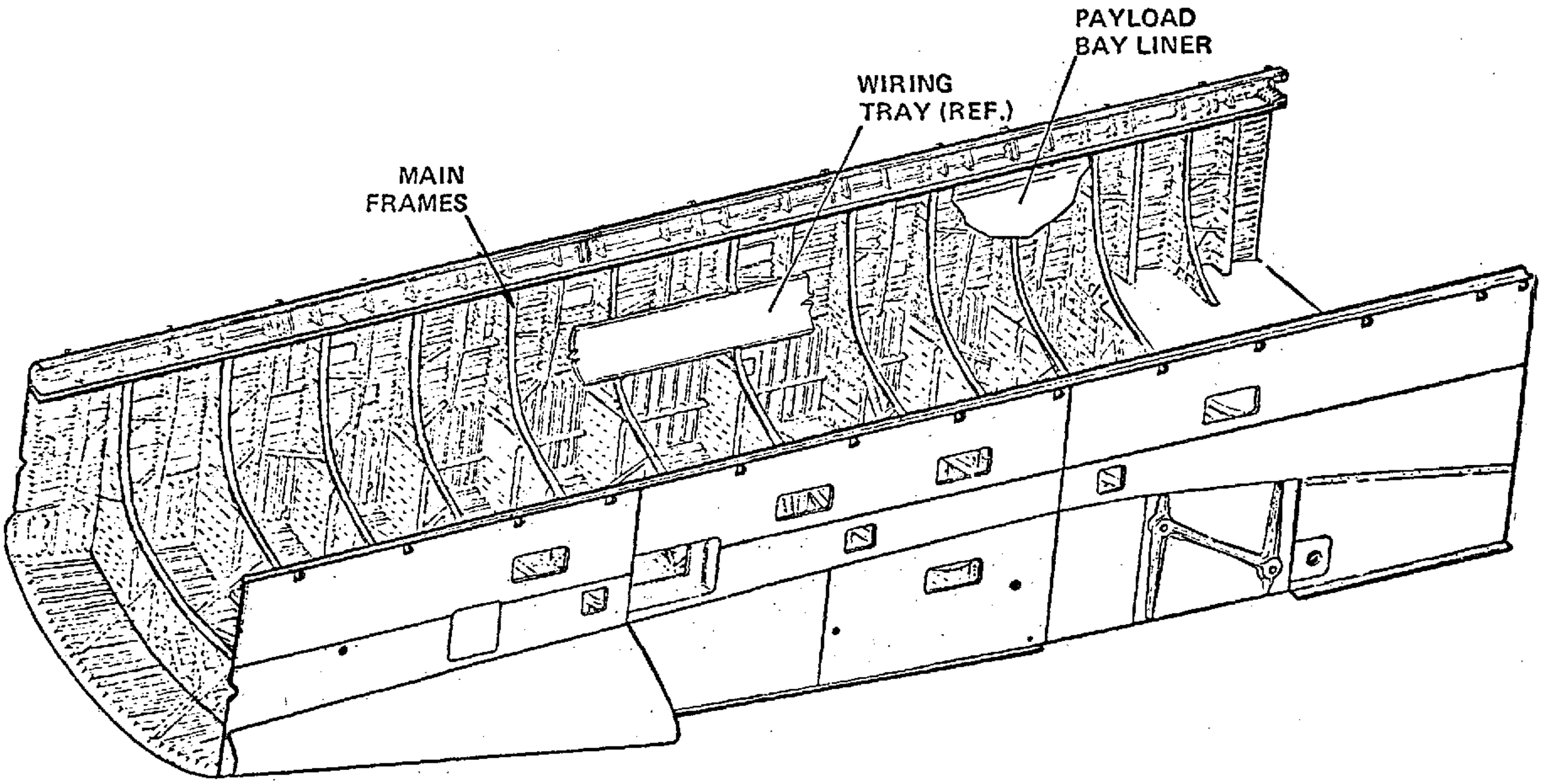


FIGURE 5.3: Orbiter Mid-Fuselage Structure/Hardware

- Payload static clearance--maintain 7.6 cm. (3 in.) from primary payload support frames
- Radiators--may be damaged by EVA crewman/cargo
- Forward and aft bulkheads--limited mounting provisions
- Weight restrictions on EVA hardware

Figure 5.4 shows the static clearance required between the payload and the primary payload support frames. Since a minimum of 5.7 cm. (2.25 in.) clearance is required for EVA handrail standoff (for grasping with gloved hand) only segmented (i.e., non-continuous) handrails can be installed under the 4.6 m. (15 ft.) diameter payloads. These handrails would be used only after the payload was deployed/jettisoned for EVA crewman payload bay equipment access. Several methods of attaching EVA mobility aids to the primary payload support frames while retaining the 7.6 cm. (3 in.) static clearance requirement are addressed in Subsections 5.1.4 and 5.1.5.

5.1.3 EVA Access Considerations for Attached Payloads

The payload bay will be configured differently for each Shuttle flight. Therefore, it would appear feasible to include provisions in the initial design for incorporating EVA mobility aids to access all on-orbit serviceable payload equipment and mid-fuselage areas. Figure 5.5 shows a handrail attachment layout for translation to the payloads and the Orbiter equipment in the vicinity of and between the primary payload support frames. Figure 5.6 illustrates the concept so that only those handrails required by the payload would be installed, thereby reducing the weight charged to the payloads. It is intended that the handrail concepts proposed by this study will be equally applicable to payloads and to the Orbiter payload bay. Typical examples of potential payload access areas and translation aid applications are shown in Figures 5.7 and 5.8.

5.1.4 Handrail Concepts--Payload Bay

The concepts developed for handrail attachment in the payload bay can be satisfied by the following: (1) hard mounting to the primary payload bay support frames using a standard bolt-hole pattern; or (2) handrail brackets attached to the support frames (no modification to the support frames required).

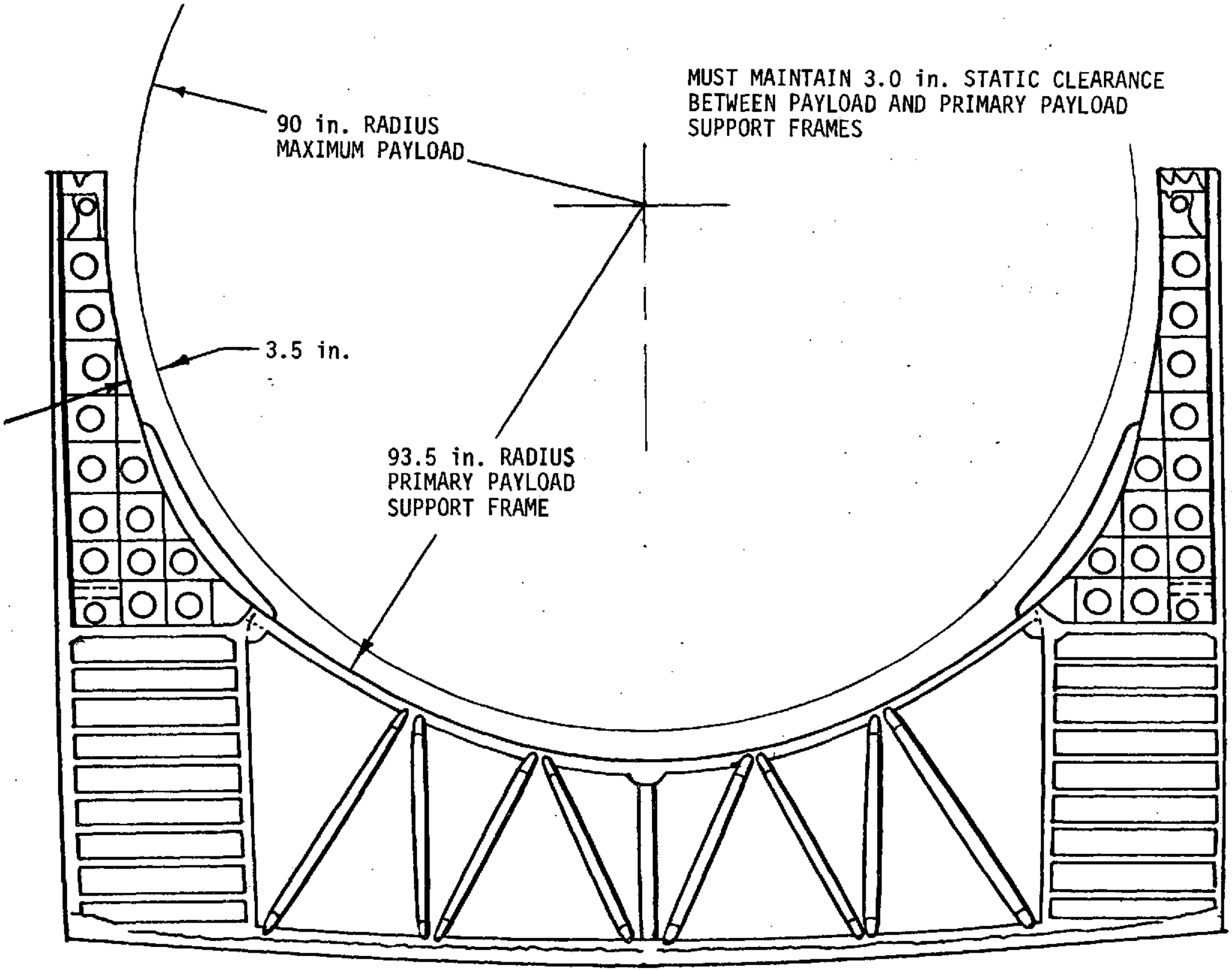
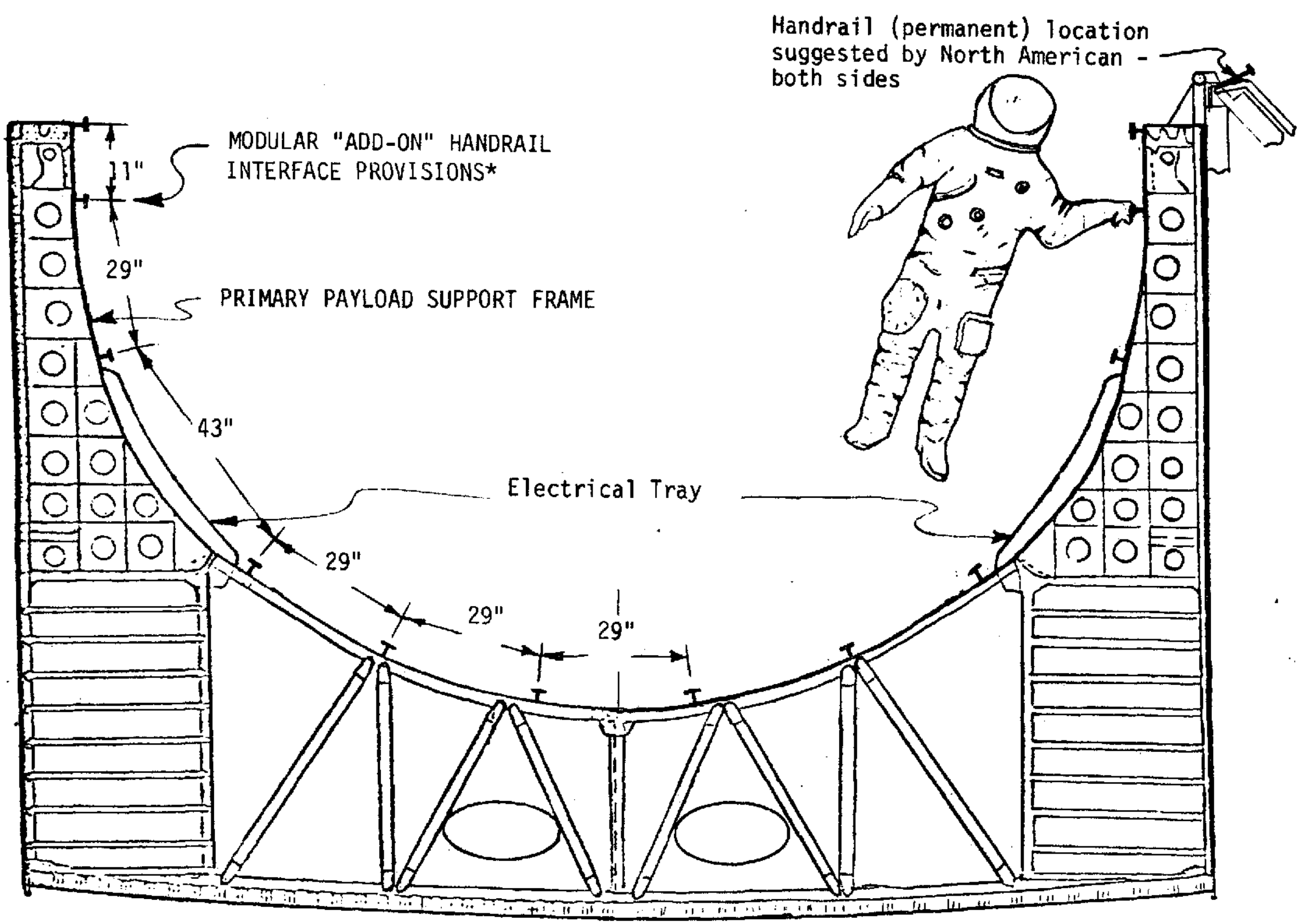


FIGURE 5.4: Payload Static Clearance Requirement



*Handrails to be Attached Prior to Launch in any Quantity as Required by Each Payload Bay Configuration

FIGURE 5.5: Recommended Handrail Attachment Locations--Payload Bay

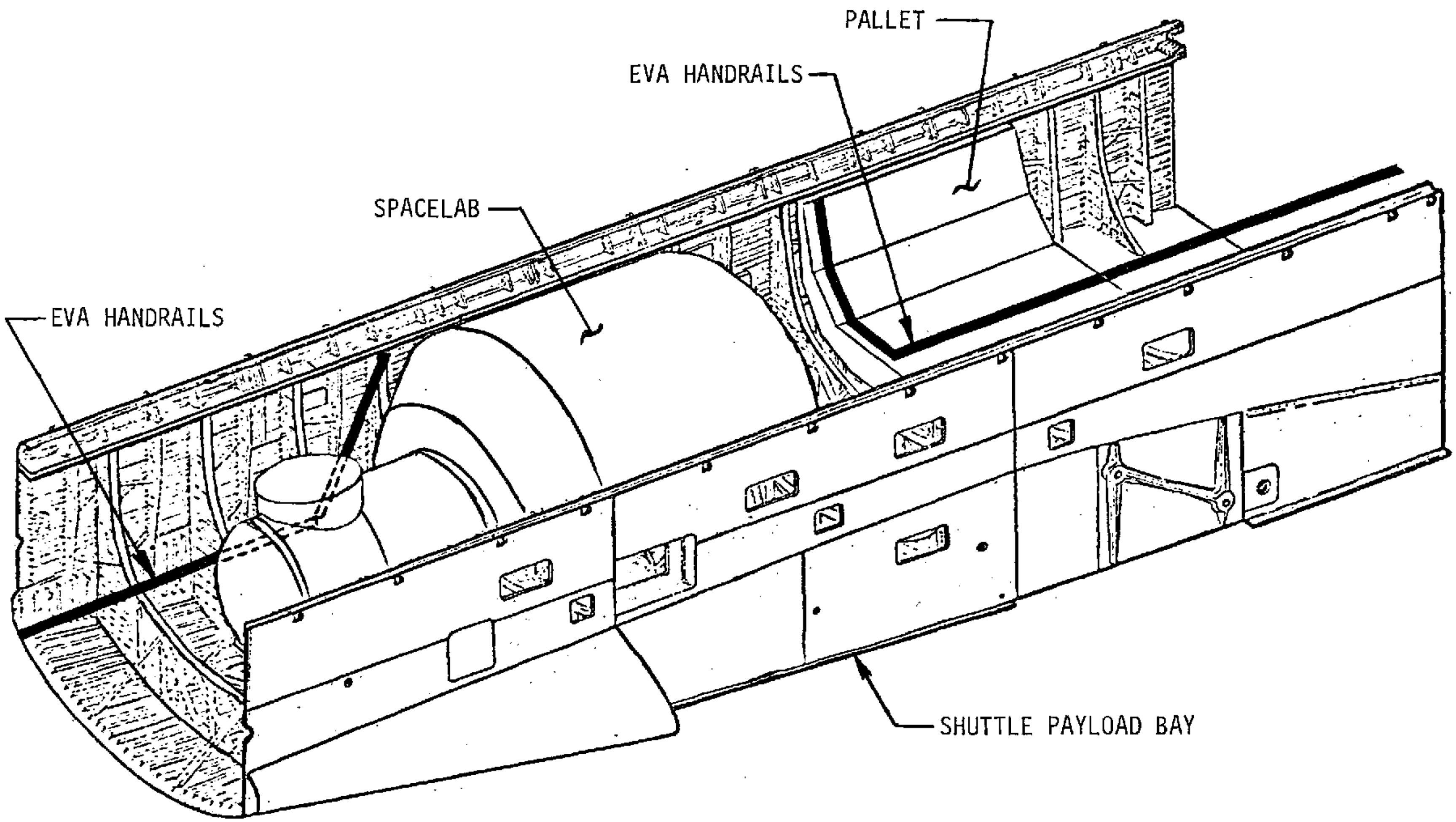


FIGURE 5.6: Typical Payload Handrail Routing--Attached Prior to Launch

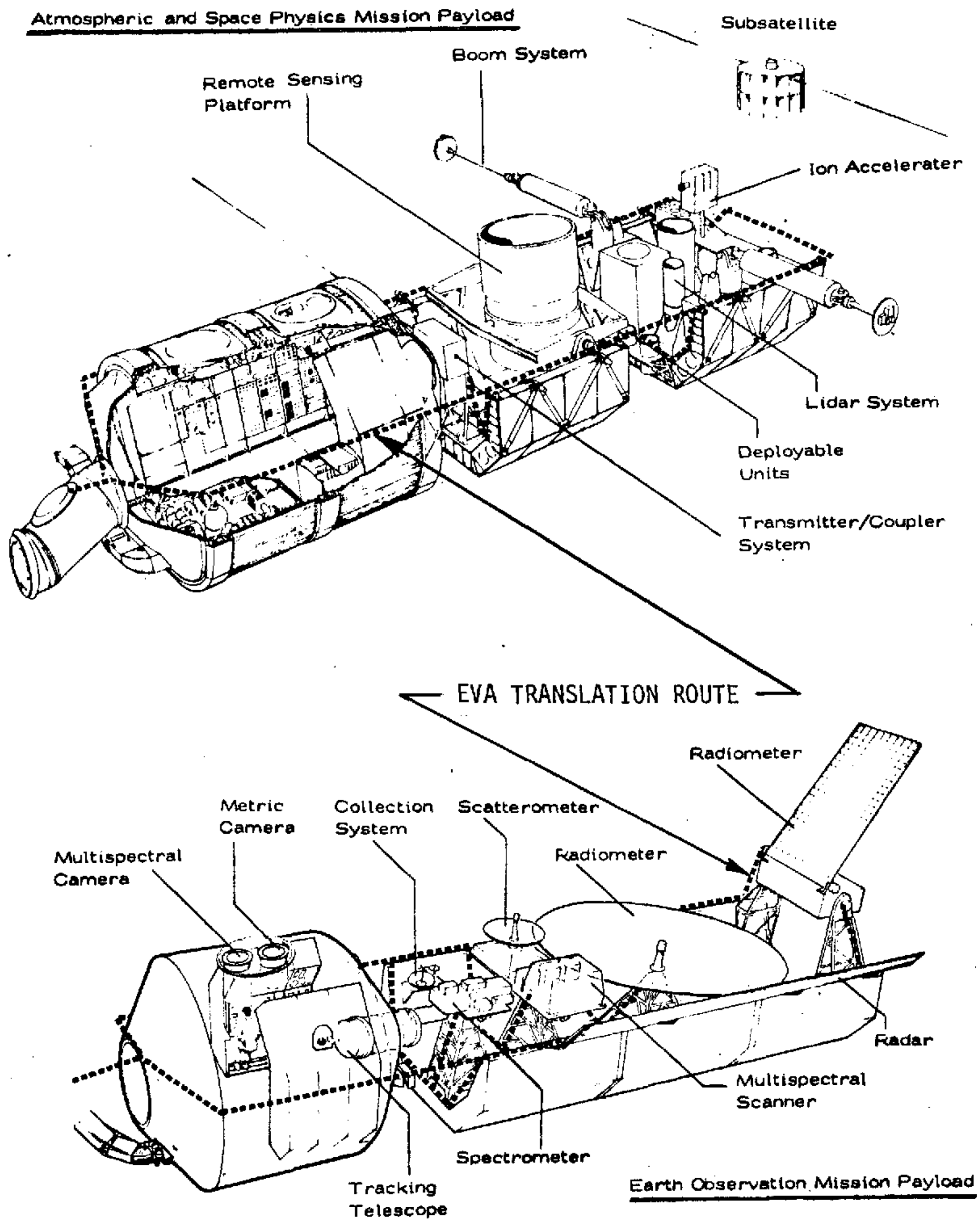


FIGURE 5.7: Typical Translation Routes to Support Sortie Payloads

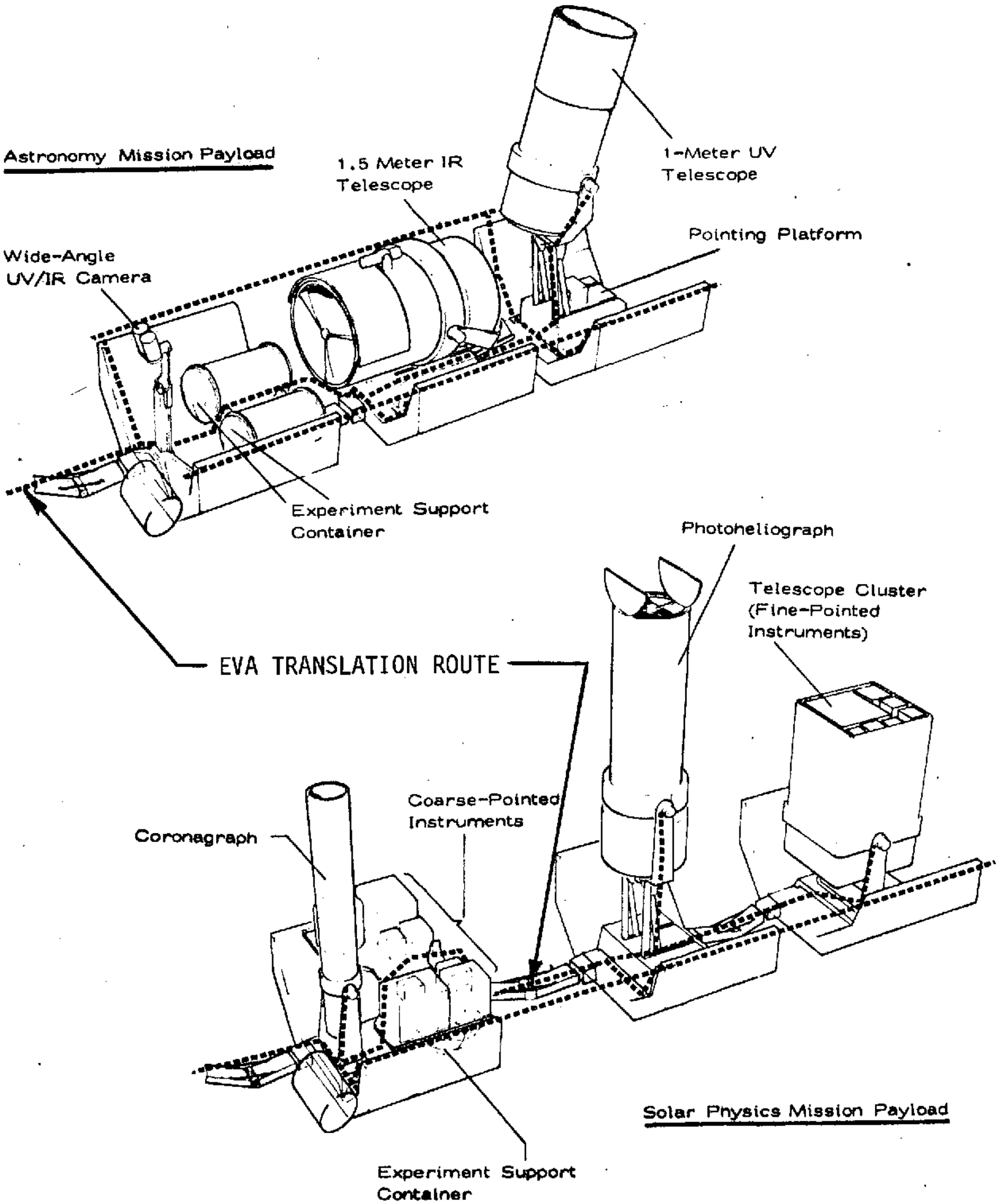


FIGURE 5.7: Typical Translation Routes to Support Sortie Payloads (continued)

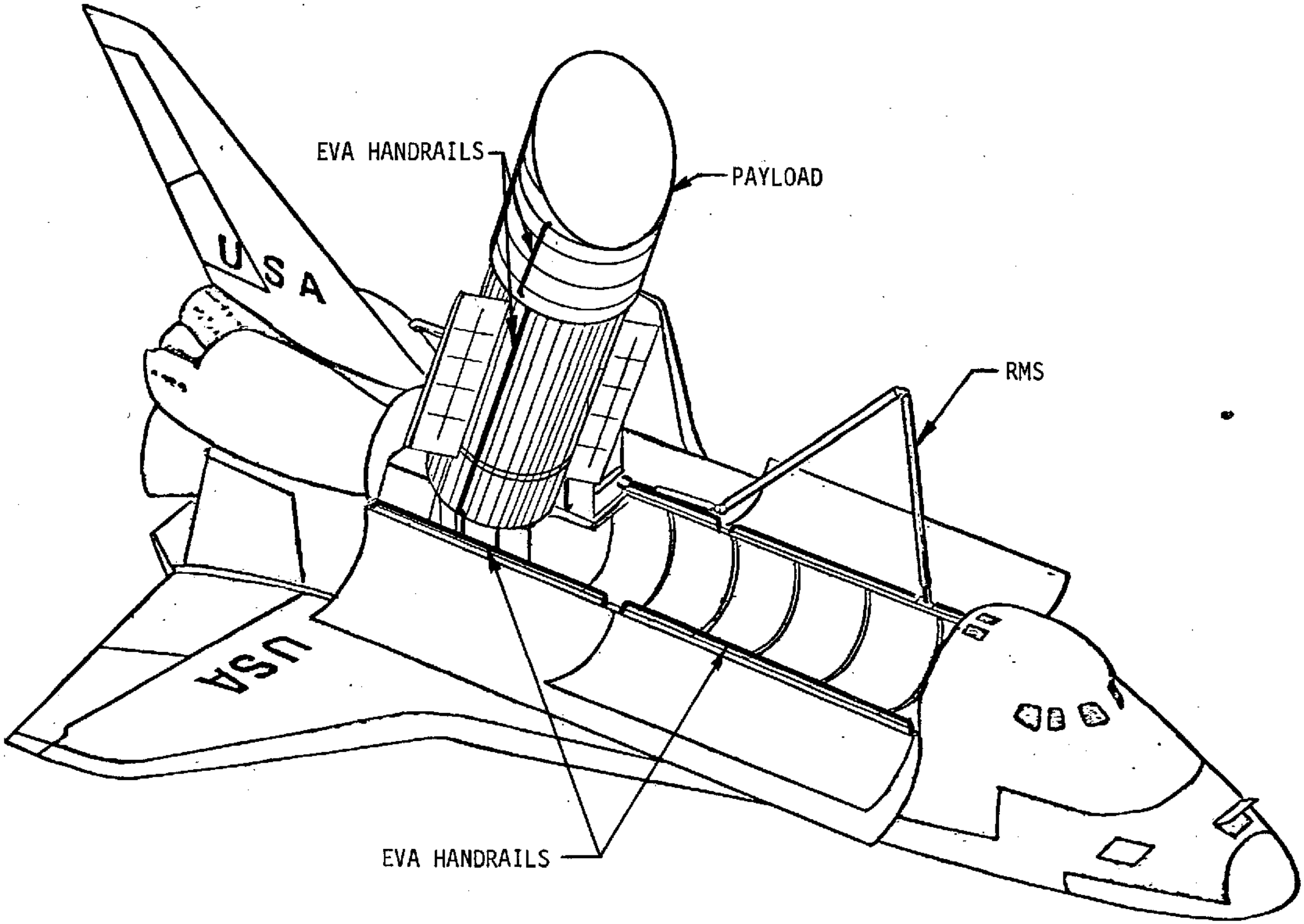


FIGURE 5.8: Typical Translation Route to Support an Automated Payload Berthed in the Orbiter Bay

5.1.4.1 Handrail Attachment Hole Pattern

The Orbiter primary support frames currently incorporate a "T" section at the top of each member. A handrail-attachment hole pattern, shown in Figure 5.9, throughout the payload bay would provide the capability to attach handrails for each payload bay configuration prior to launch. The hole pattern may also be used to provide rigid nails that could replace the presently proposed "lifeline" and permit the static clearance requirement of 7.6 cm. (3 in.). Two attachment concepts are shown in Figure 5.10. The concept for rigid mounting assumes no significant structural or thermal deflection. The shock-mount concept compensates for structural deflection.

5.1.4.2 Handrail Configuration Concept--Rigid Mounting

The Skylab cross-section configuration may be applicable for Space Shuttle use (see Figure 5.11). The simplest attachment arrangement would consist of bolting the handrail directly to a supporting structure. The handrails may be fabricated from round tubular stock and formed into the desired cross-section or from extruded sections. Solid aluminum inserts could be welded into the tubular handrail sections at each end. The mounting holes in the solid insert can be elongated to allow for structural deflection when mounted with spring washers. The handrails could also be designed with a telescoping joint or other techniques to absorb deflection loading. The handrails may be more rigidly attached through direct bolting if structural deflection is not a factor.

5.1.4.3 Handrail--Standoff Concept

The accompanying Figure 5.12 suggests a simple, low-cost concept for attaching the handrails to the Shuttle Orbiter primary payload support frames using the bolt-hole method discussed earlier. The system consists of a drilled cylindrical aluminum bar and the Skylab handrail bolted directly to the frames. The handrail and standoff would be bolted in the payload bay or to the payloads as required prior to launch. NASA design specifications

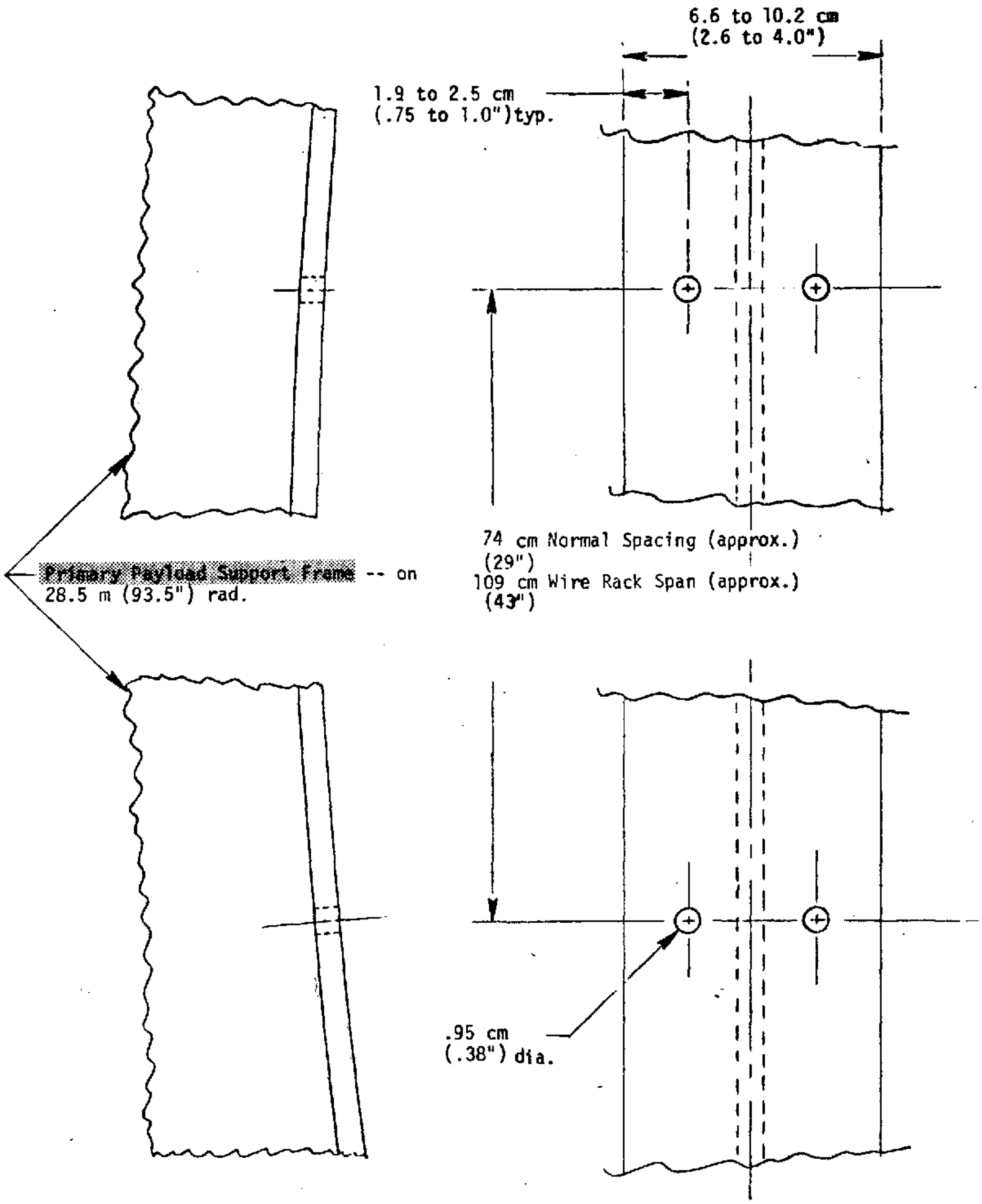


FIGURE 5.9: Handrail Attachment Hole Pattern

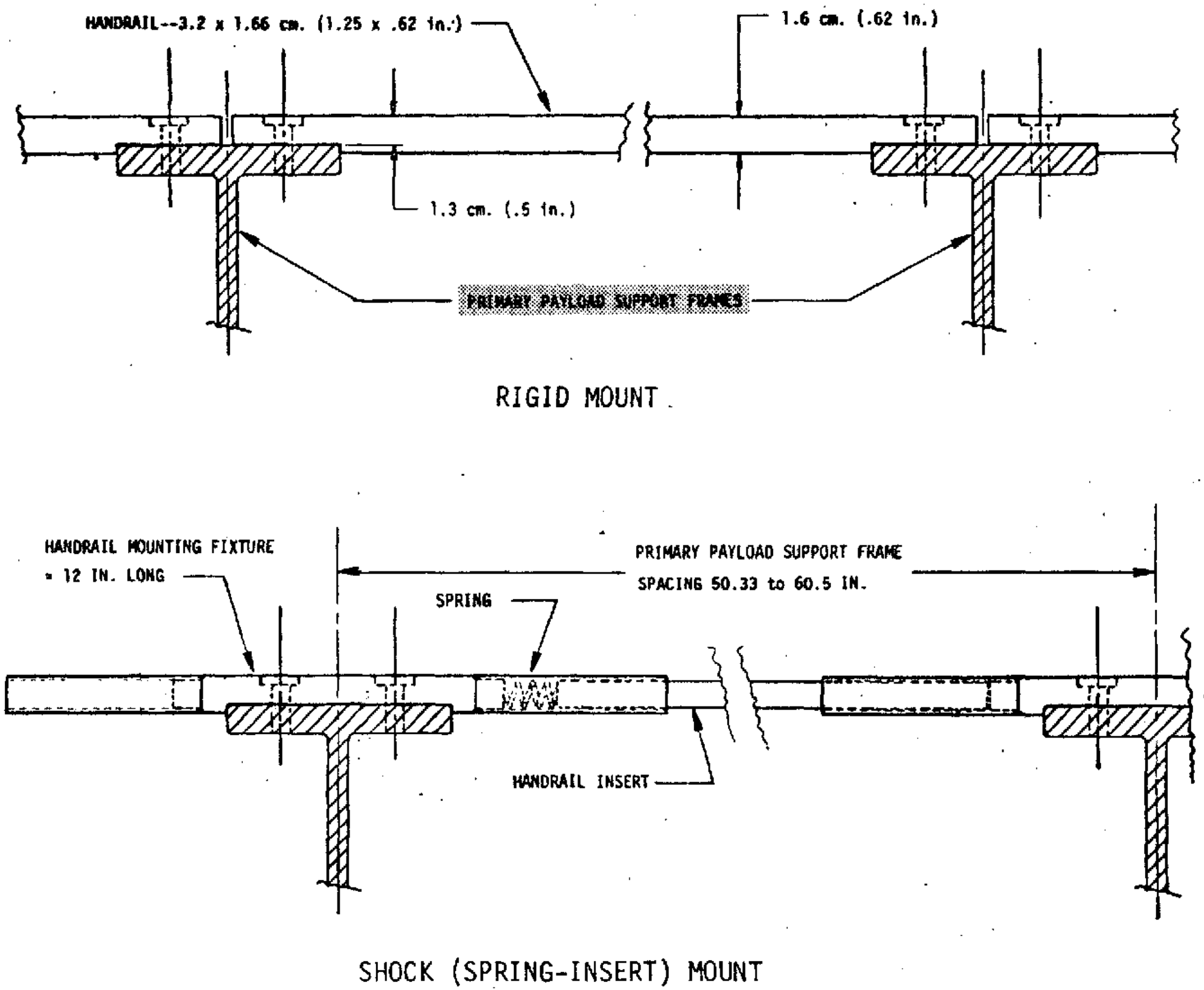


FIGURE 5.10: Typical (Under Payload) Handrail Mounting Concepts

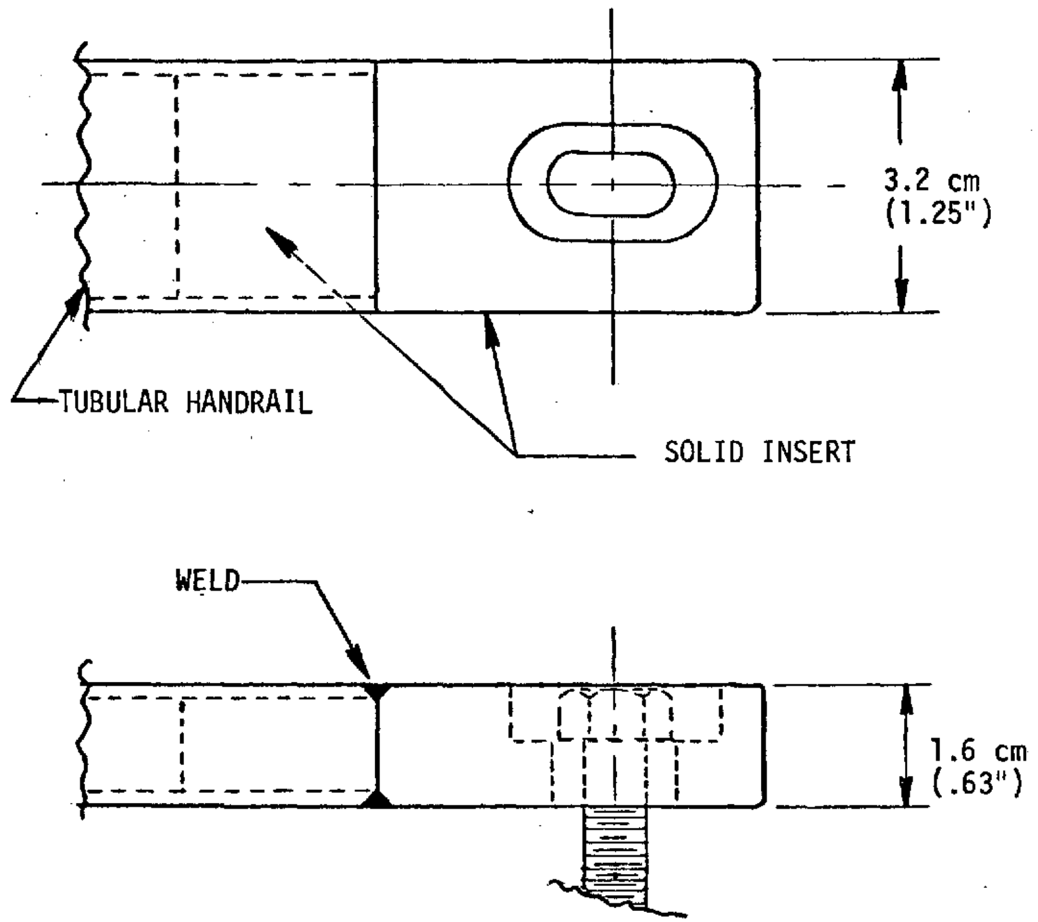


FIGURE 5.11: Handrail Configuration Concept--Rigid Mounting

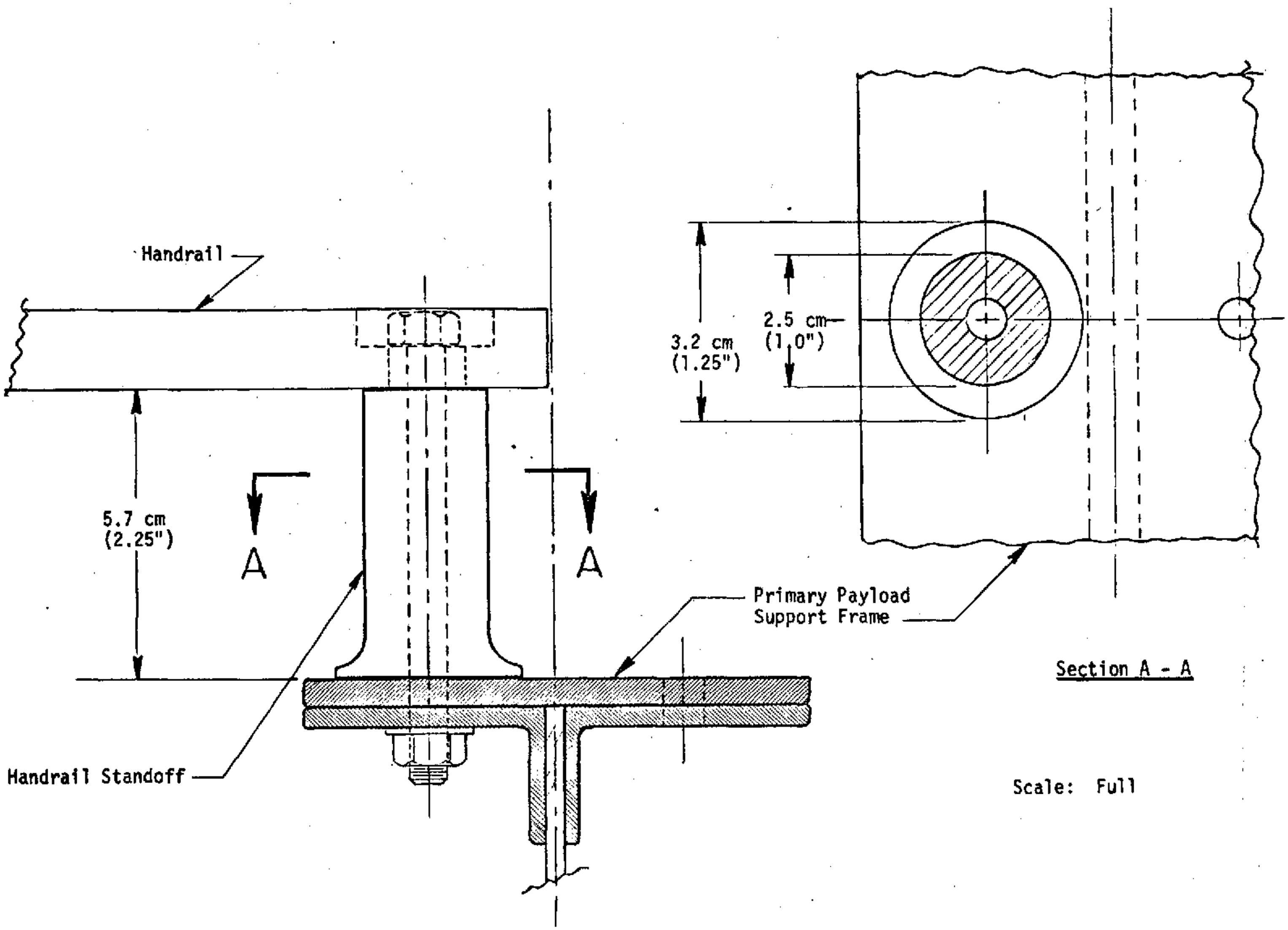


FIGURE 5.12: Handrail--Standoff Mounting Concept

require 5.72 cm. (2.25 in.) clearance between the handrail and the mounting surface for EVA mobility aids. Standoffs of various lengths to meet EVA requirements would be easily fabricated.

5.1.4.4 Handrail Attachment Bracket Concept

An alternate attachment concept (preliminary) is recommended if a bolt-hole pattern cannot be provided in the Orbiter bay primary payload support frames. Simple brackets that bolt to any point along the primary payload support "T" frame sections would offer versatile EVA routes within the payload bay. Figure 5.13 shows a set of brackets for installing continuous handrails up to a payload interface or through the payload bay. The brackets and handrails would be installed prior to launch as required. The end attachment bracket for terminating the handrail at an intermediate primary support frame is shown in Figure 5.14. Similar brackets may be used for attaching the handrails to payload structures or Orbiter bulkheads.

5.1.4.5 EVA Handrail Weights--Proposed Concepts

Preliminary calculations of the handrail weights were performed for both the cylindrical standoff system (bolted directly to the primary support frames) and the attach bracket handrail system. Based on the material characteristics shown in Table 5-1, a weight penalty of approximately 9 kg. (20 lbs.) is required for an 18.3 m. (60 ft.) run of handrail bolted to the primary payload support frames. The same 18.3 m. (60 ft.) run of the attach bracket handrail will have a weight penalty of approximately 10 kg. (22 lbs.).

5.1.4.6 Portable Handrail Concepts

Crewman mobility aids may be required in the payload bay after deployment or mandatory jettison of a payload. A portable handrail system may be deployed by the EVA crewman if quick connect/disconnect provisions are incorporated into the handrail design. One such concept is shown in Figure 5.15 which features a captive "floating" pip-pin configuration.

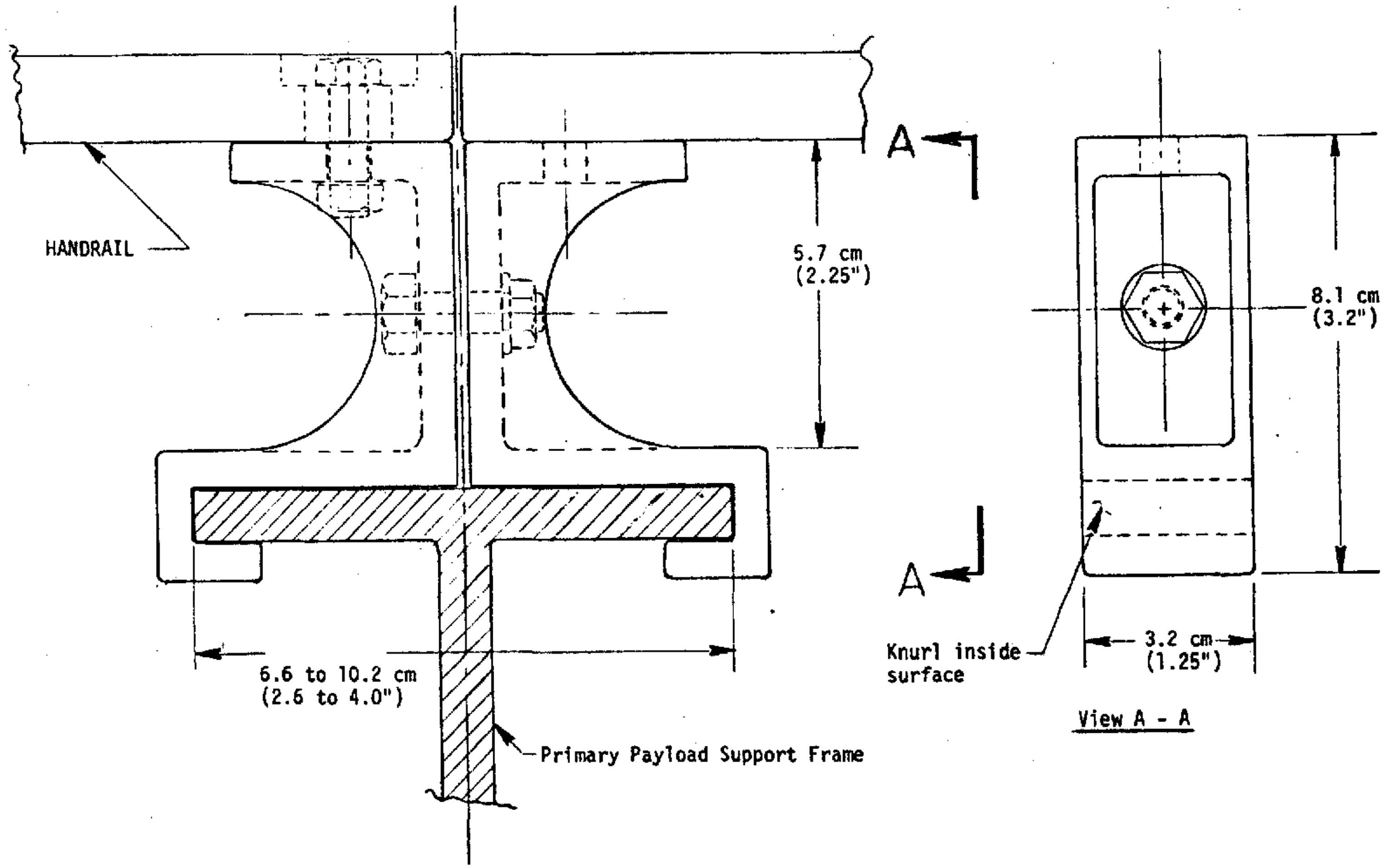


FIGURE 5.13: Handrail Attach Bracket Concept--Continuous Rails

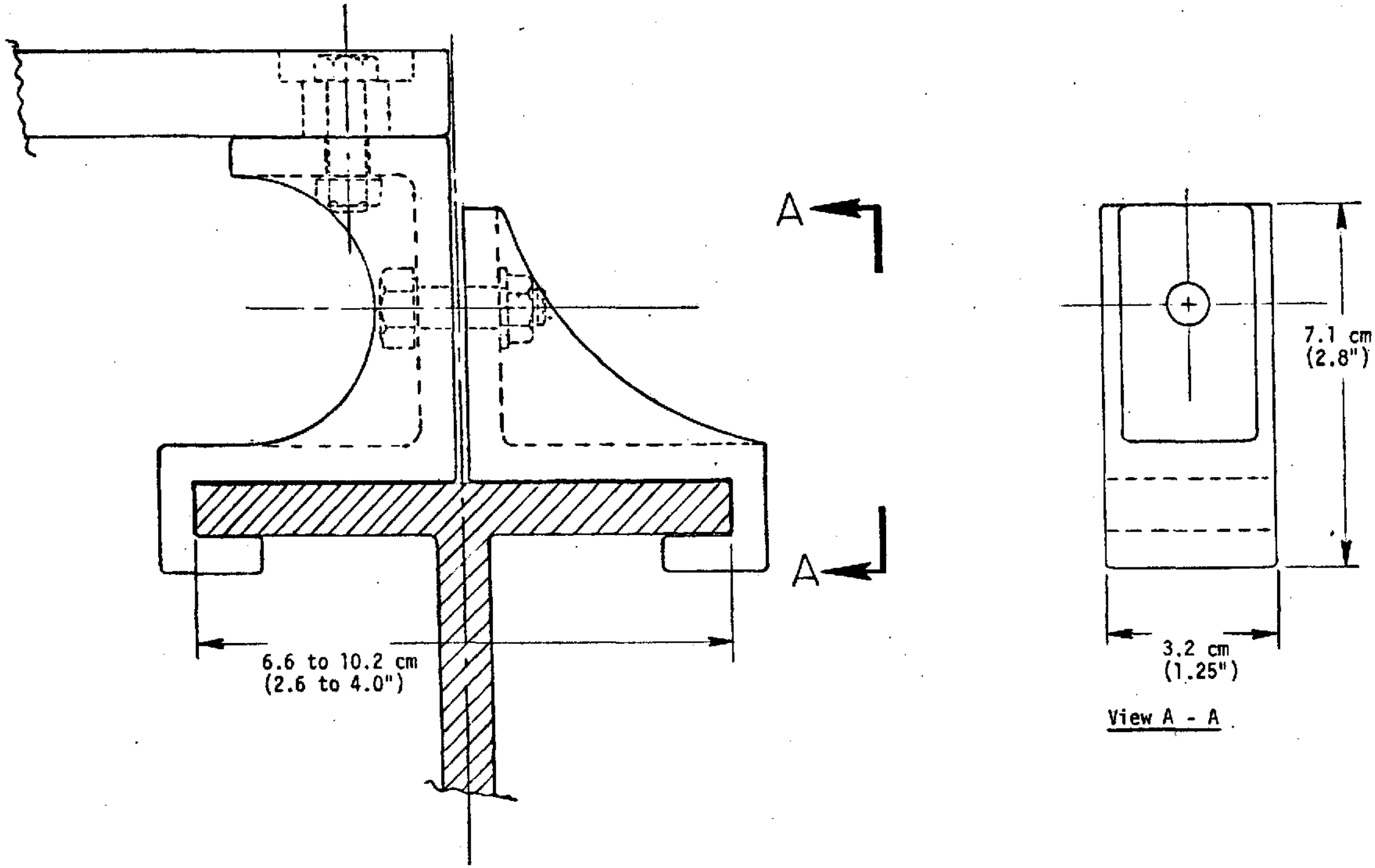


FIGURE 5.14: Handrail Attach Bracket Concept--End Attachment

TABLE 5-1: EVA Handrail Weights--Proposed Concepts

ITEM	WEIGHT		REMARKS
	kg/m	lb/ft	
Aluminum Handrail	.342	.230	• Calculations based on 2.86 cm (1.125") O.D. circular tubing with wall thickness of .17 m (.065") formed into standard handrail configuration
	kg	lb	
Cylindrical standoff package	.106	.234	• Includes bolt, nut, washer and rail insert • Use 1.9 cm (.75") O.D. Al bar with .96 cm (3/8") dia. hole • .79 cm (5/16") dia. bolt • Assume all aluminum hardware
Clamp-on standoff package	.14	.30	• Includes bolts, nuts, washers and rail insert • Assume .68 cm (3/16") Al plate • .79 cm (5/16") dia. bolts • All Al hardware
18.3 m (60 ft.) Al handrail system (cylindrical standoffs)	9.08	20.02	• Assumes two standoffs per primary payload support frame plus 2 bulkhead fittings
9.1 m (30 ft.) Al handrail system (clamp-on standoffs)	4.94	10.80	• Assumes two standoffs per primary payload support frame plus 1 bulkhead fitting

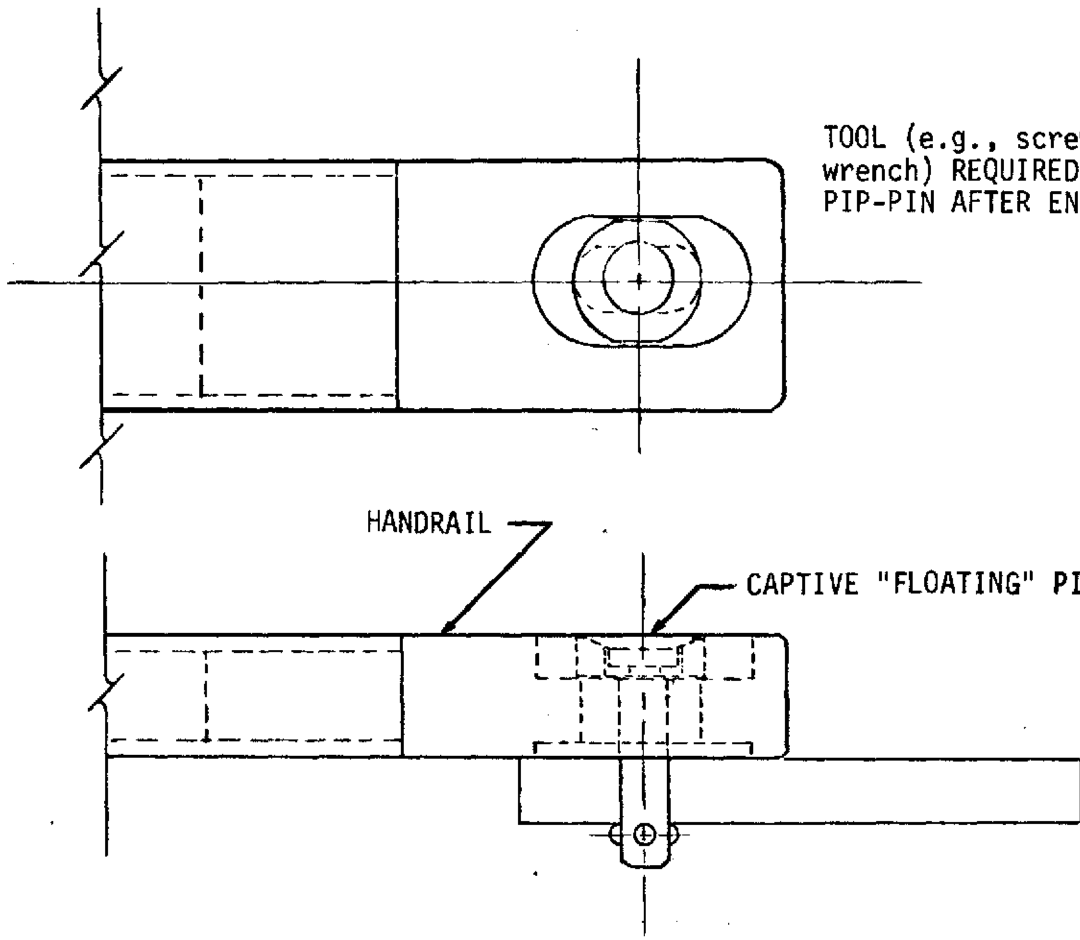
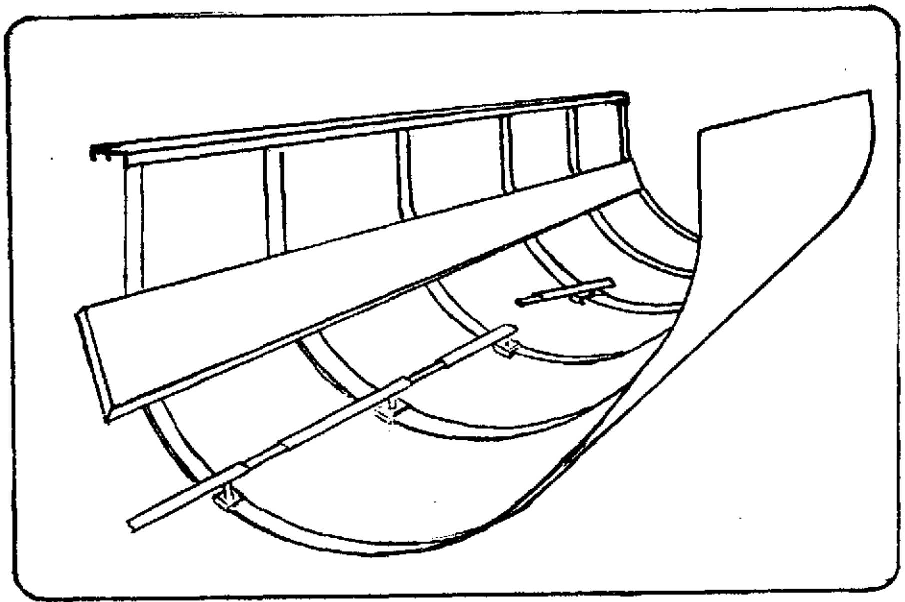


FIGURE 5.15: Captive "Floating" Pip-Pin Handrail Mounting Concept

Several concepts were considered for providing a portable handrail kit to be installed/deployed on-orbit by the EVA crewman. A typical kit would consist of a sufficient number of handrails and standoffs to erect a translation route through or to any point within the payload bay and to payloads extending from the bay. The concept shown in Figure 5.16 includes extendible handrail inserts which allow adjustment from 1.3 m. (50 in.) to in excess of 1.6 m. (61 in.). The portable handrails would be deployed in contingency situations to a malfunctioning payload or to an Orbiter subsystem after the payload was deployed or jettisoned. In Figure 5.17, a quick connect/disconnect standoff concept is depicted for attaching the portable handrail to the primary payload support frames. The handrail is installed by placing the standoff on the tee section of the primary payload bay support frames or similar payload structure and temporarily hand-tightening the unit. The handrail can then be inserted into the standoff bracket and used as a lever arm to tighten the bracket. The assembly features a ratchet device with clockwise, counter-clockwise, and neutral (free-wheeling) positions to aid installation and removal. A handrail capture latch interfaces with the handrail extension/insert to provide a continuous handrail system. The push-to-release mechanism prevents the handrail from being inadvertently dislodged from the standoff and secures the handrail extension.

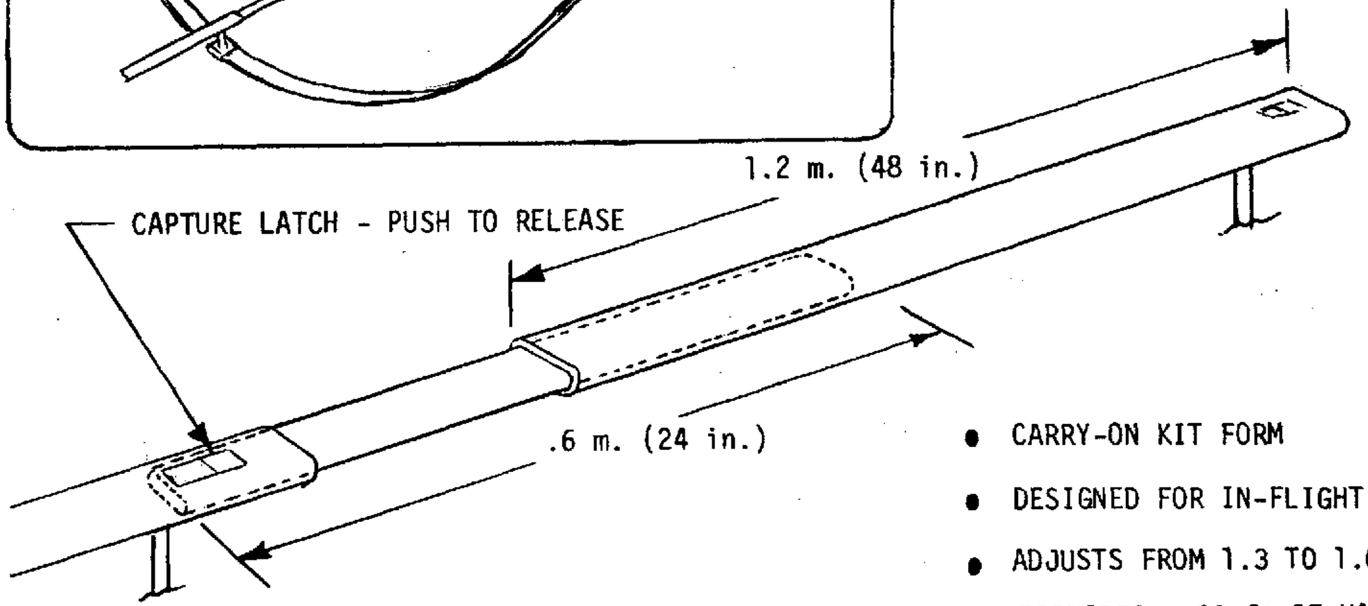
The details of the standoff attachment mechanism have not been developed since hardware design is not within the contract scope. However, Figure 5.18 shows a possible design approach for that portion of the standoff mechanism which attaches to a structural "T" member. The ratchet mechanism housed in the body of the standoff may consist of a modified off-the-shelf unit. The dimensions shown are approximate for a typical unit.

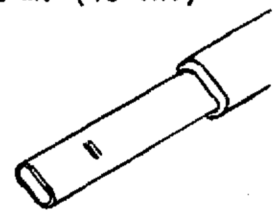
Preliminary envelope stowage dimensions for packaging the portable handrail kit for Orbiter stowage are shown in Figure 5.19. The preliminary concept requires a package size approximately 122 x 25 x 14 cm. (48 x 10 x 6 in.) which could be stowed in the payload bay near the EVA hatch. The approximate stowage volume is 4,270 cm^3 ($\approx$1 ft^3).



PORTABLE HANDRAIL KIT STOWAGE CONTENTS

- 17 RAILS (INCLUDES 4 SPARES)
- 18 MOUNTING BRACKETS (INCLUDES 4 SPARES)
- MOUNTING FIXTURE AND STRAPS
- STOWAGE ENVELOPE - 14.2 cm. (6.0 in.) x 25.4 cm. (10.0 in.) x 1.2 m. (48 in.)





- CARRY-ON KIT FORM
- DESIGNED FOR IN-FLIGHT INSTALLATION
- ADJUSTS FROM 1.3 TO 1.6 m. (50 to 61 in.)
- PROVIDES ≈ 90 ft OF HANDRAIL

FIGURE 5.16: Portable Handrail Concept--On-Orbit Installation

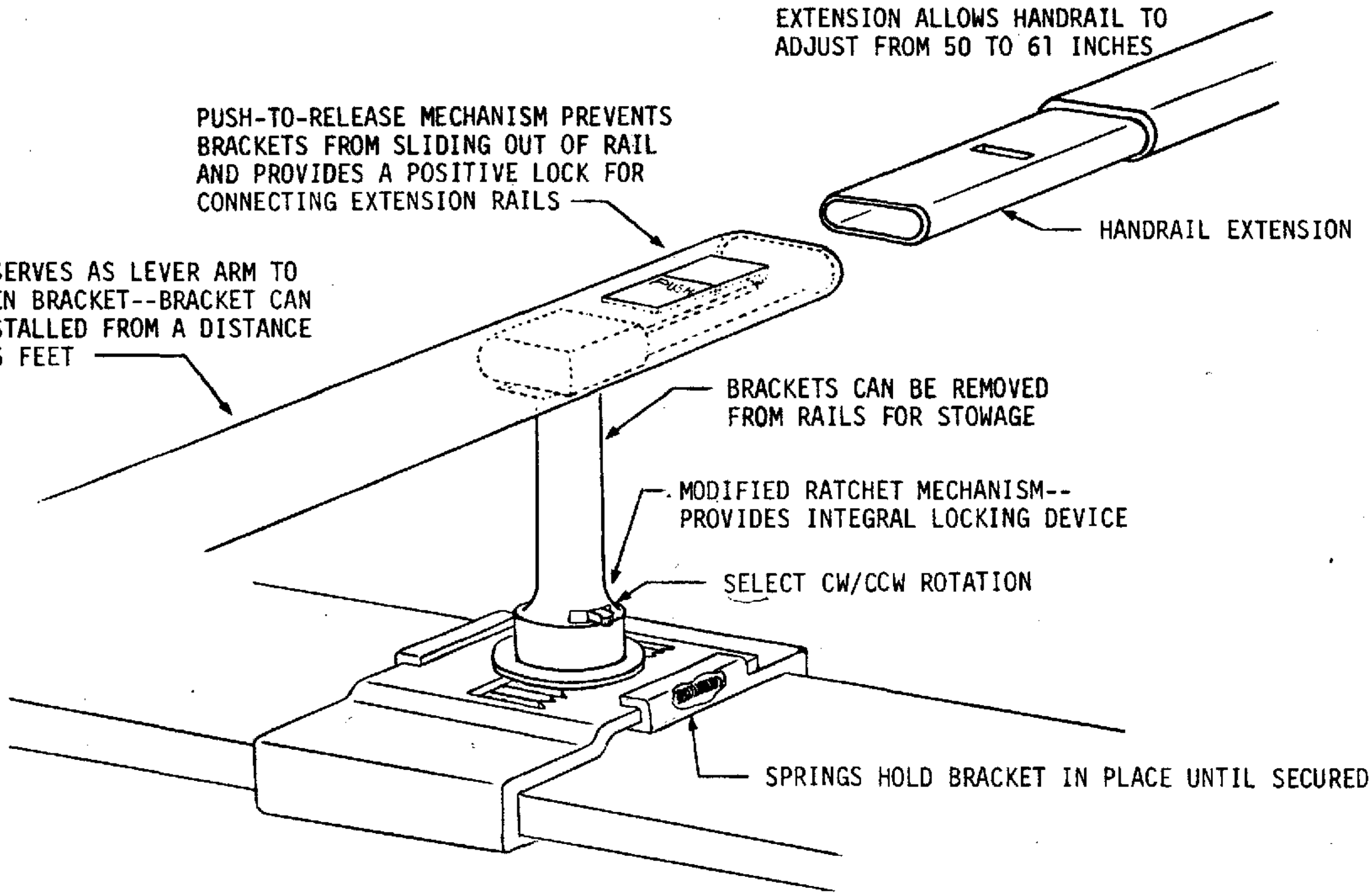


FIGURE 5.17: Portable Handrail Attachment Concept

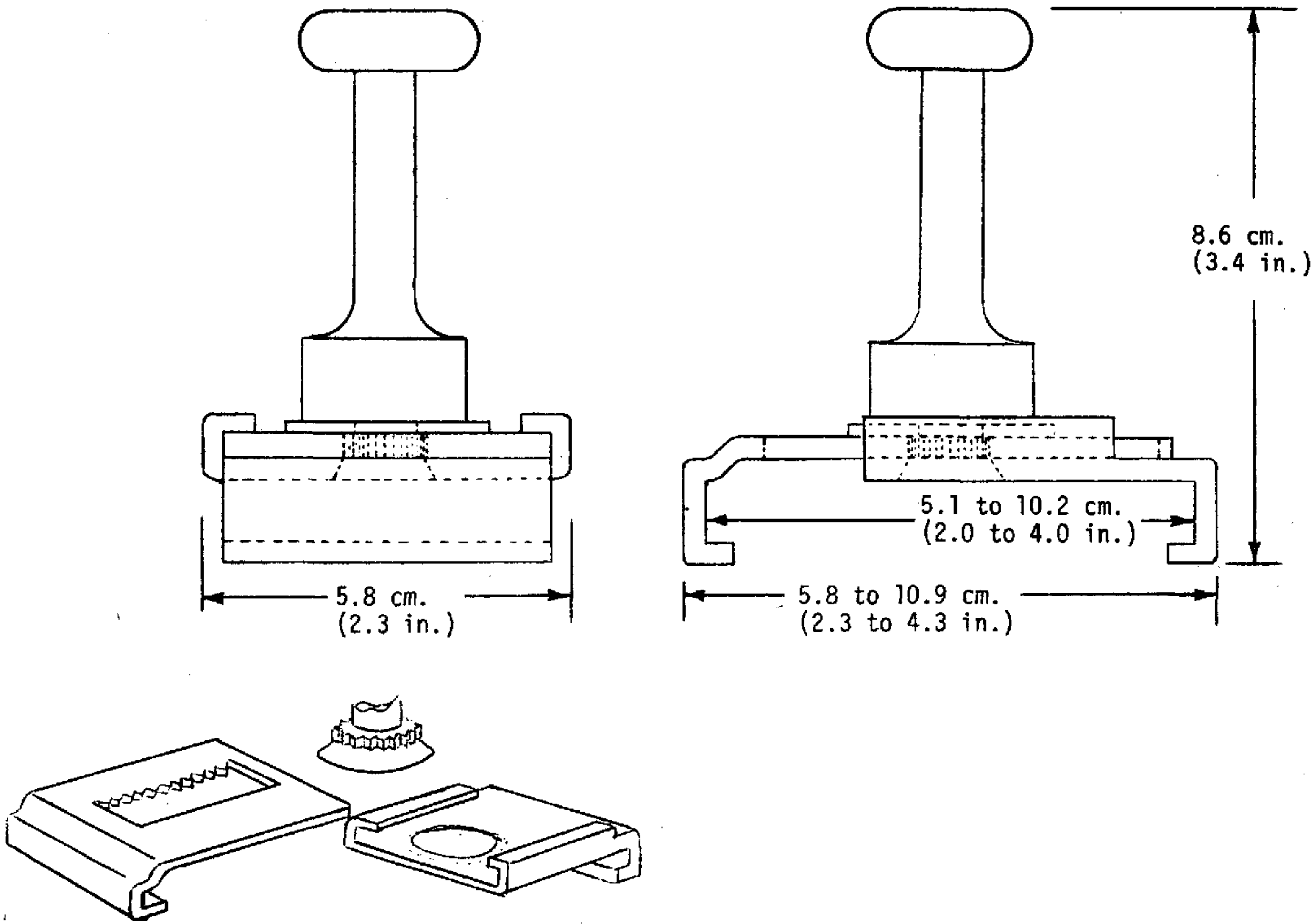


FIGURE 5.18: Portable Handrail Attachment Design Suggestions

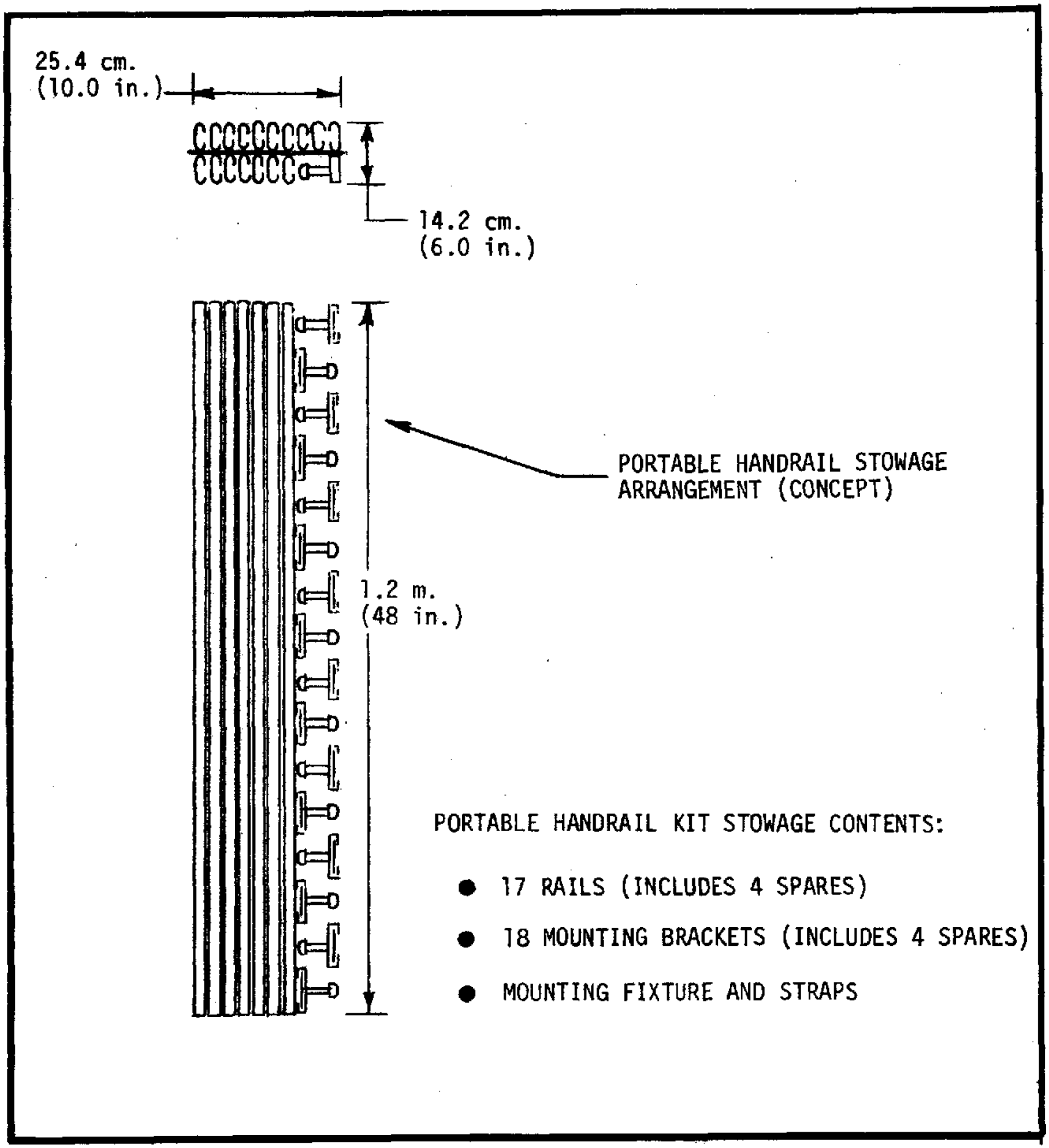


FIGURE 5.19: Portable Handrail Kit Stowage Envelope

5.1.5 Orbiter Bulkhead Handrail Concepts/Locations

Several concepts have been proposed for locating crewman mobility aids to provide access to the forward and aft Orbiter bulkheads. Handrail configuration concepts and locations are suggested in subsequent sections. Several of the handrail attachment methods recommended for the payload bay are considered applicable to the bulkheads.

5.1.5.1 Forward Bulkhead Handrail Locations

The Orbiter forward bulkhead was studied in detail relative to EVA access requirements to bulkhead-mounted equipment and to mobility aids transversing the payload bay. Concept 1 shown in Figure 5.20 provides access to all the major equipment interfaces including the payload bay door latch fittings, door sealing surfaces, observation window, etc. Observation of the forward RCS and star tracker doors may also be accomplished. The upper handrail may not require a continuous rail or be in the exact location shown due to the bulkhead-mounted Orbiter support hardware. (However, the requirement for crewman mobility aids in this area should be determined prior to baselining the forward bulkhead handrail locations.)

An alternate concept is shown in Figure 5.21 for forward bulkhead translation and equipment access. The concept eliminates the handrails extending directly from the EVA hatch to each payload bay door and replaces them with a vertical handrail, handhold, and curved handrail near the aft viewing windows. This concept provides the same access to the upper bulkhead area as the previous concept. The handrail system would require slightly less handrail length than the previous concept.

5.1.5.2 Aft Bulkhead Handrail Locations

The concept shown in Figure 5.22 provides access to the major equipment, panels, wire trays, etc. located on the Orbiter aft bulkhead. The concept repositions the curved handrail across the upper portion of the bulkhead and

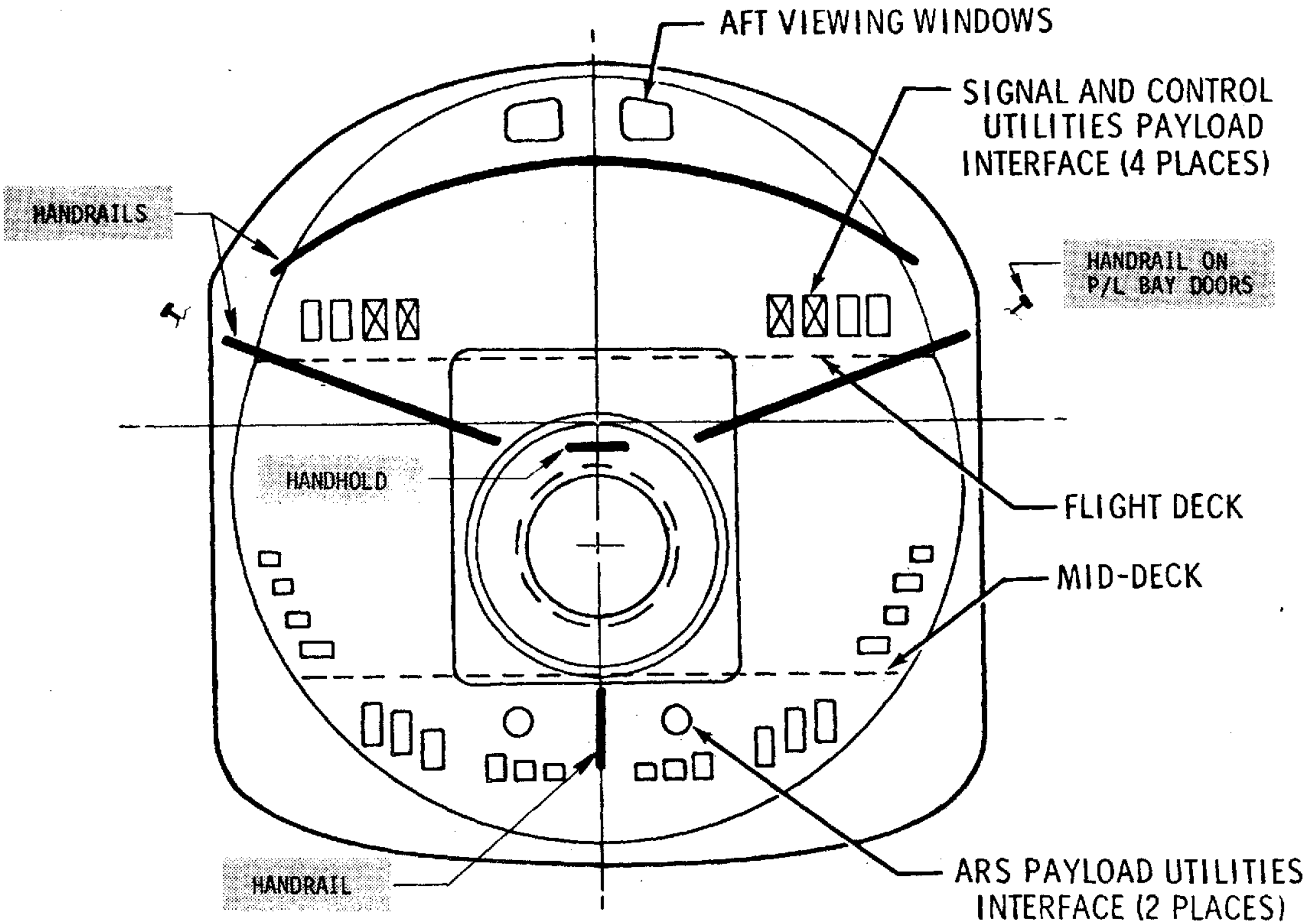


FIGURE 5.20: Forward Bulkhead Handrail Suggested Locations--Concept 1

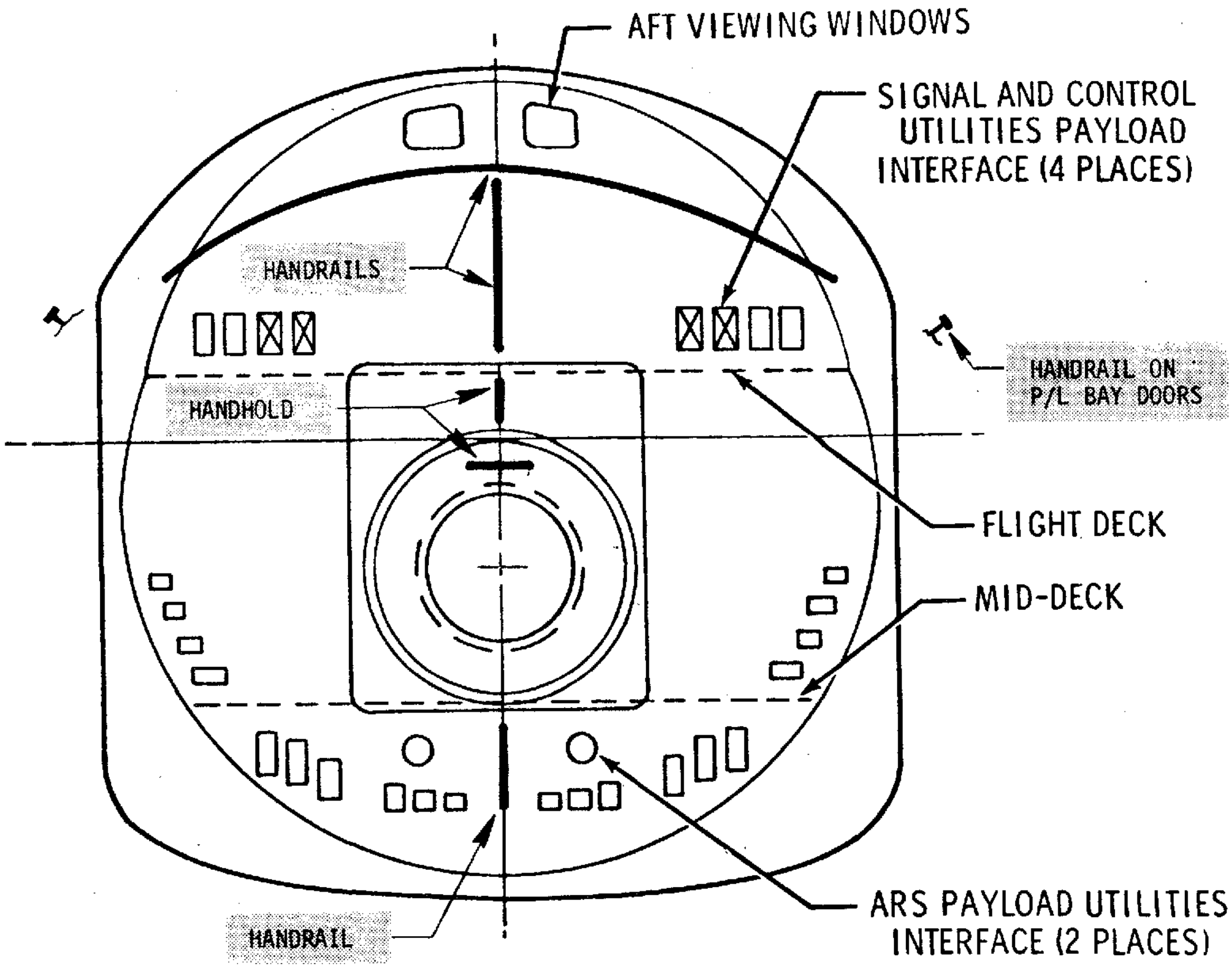


FIGURE 5.21: Forward Bulkhead Handrail Optional Locations--Concept 2

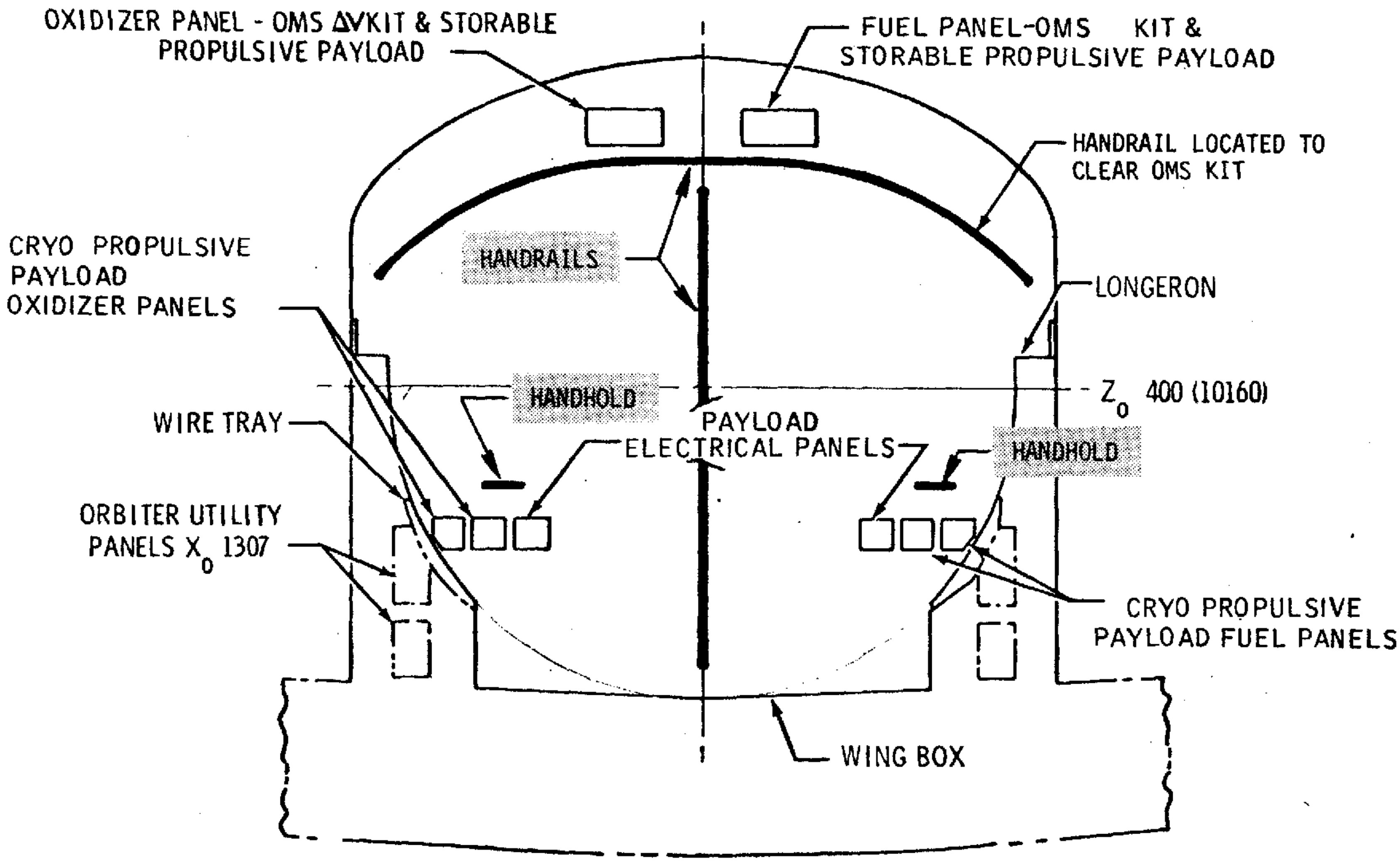


FIGURE 5.22: Aft Bulkhead Handrail Suggested Locations

adds two handholds to the currently proposed NASA/Rockwell International concepts.

5.1.6 Payload Pallet Mobility Aid Interface

Attachment of EVA mobility aids to the payload pallets does not appear to be a significant problem under the current design. There are 29 "pickup" points provided on each pallet to rigidly secure EVA/experiment hardware. Inserts may also be provided on each of the honeycomb floor panels for attaching EVA support equipment. In addition, the honeycomb floor panels may be used for attaching experiment servicing equipment and EVA workstations when only relatively low stresses/loading are required. The current Shuttle pallet structural configuration is shown in Figure 5.23.

5.1.7 RMS-Crewman Mobility Aid Concept

Since the RMS is in the conceptual design phase, the length, diameter, and precise motions of the RMS members are not available. The capability of the RMS to accommodate attachment of handrails and workstations has not been fully addressed by NASA. However, the RMS currently appears to be a viable candidate for providing an access route to many areas of the Orbiter and to payloads extending from the payload bay. Under the present concept, the RMS end effector is required to be attached to a fixed structure for sufficient boom rigidity (see Space Shuttle System Payload Accommodation, JSC 07700, Volume XIV, Revision C, July 3, 1974). In addition to supplying a translation route, a portable EVA workstation attached to the wrist member of the RMS would provide worksite accommodations for the crewman. As presently conceived, the EVA workstation would be stowed near the EVA egress hatch and secured to the RMS wrist member before the arm is maneuvered to and attached at the worksite. The crewman would then translate via the handrails and ingress the workstation.

Figures 5.24 and 5.25 indicate several basic attachment interfaces that may suffice for handrail/workstation placement. Consideration should be given

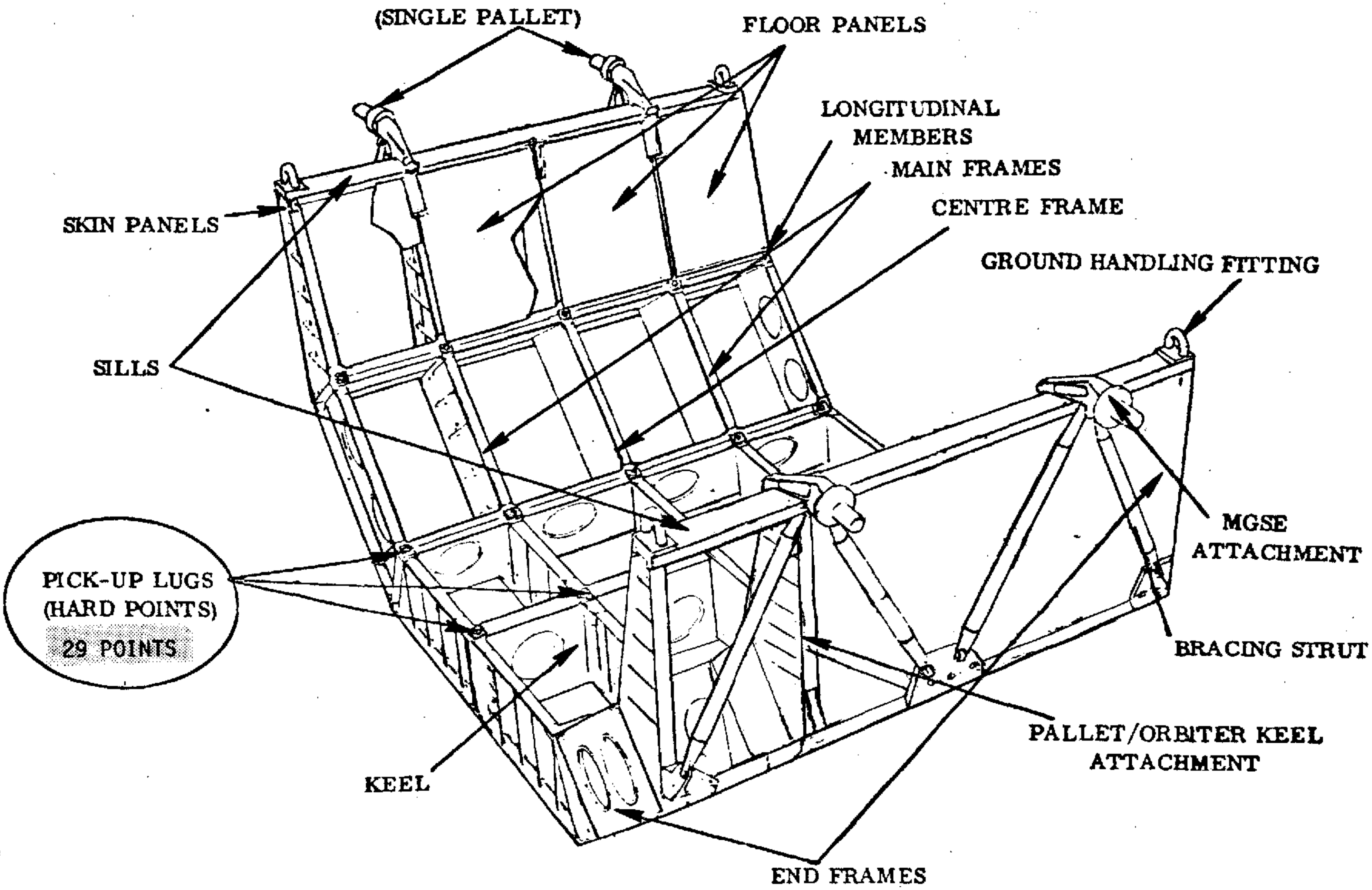


FIGURE 5.23: Shuttle Pallet Typical Configuration

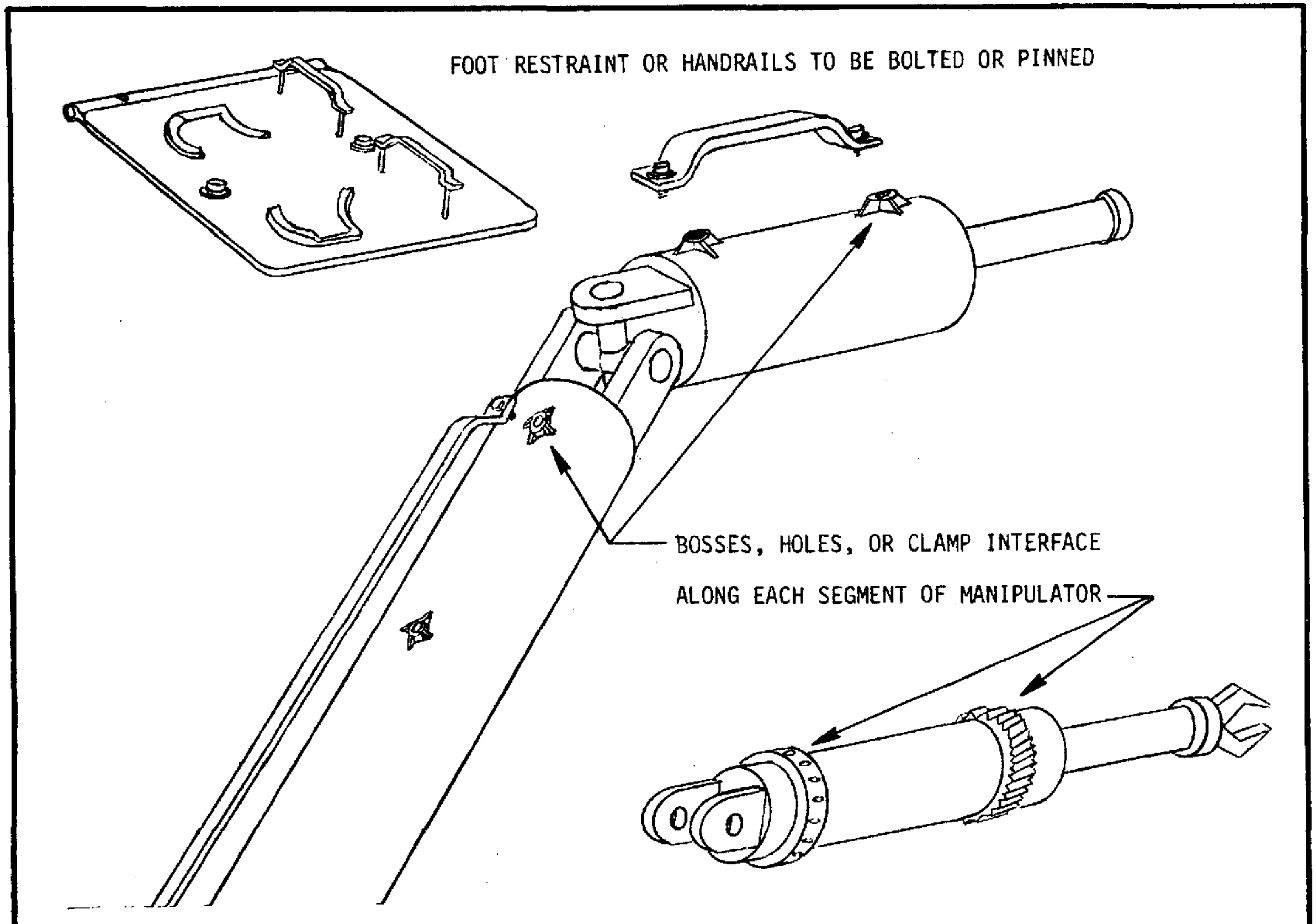


FIGURE 5.24: Handrail/Workstation to RMS Interface Concepts

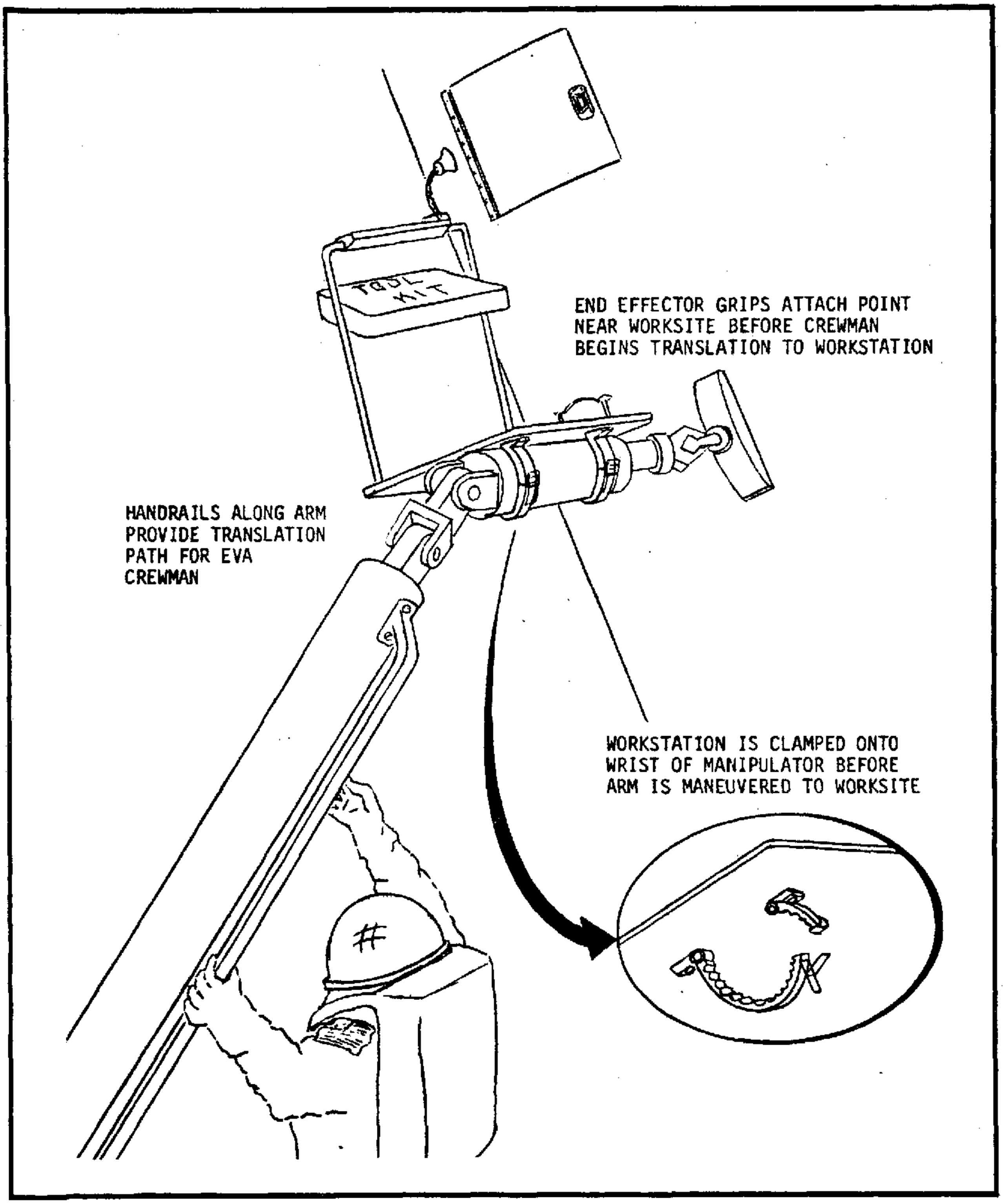


FIGURE 5.25: RMS-EVA Translation and Worksite Accommodation

to utilizing the RMS in combination with the EVA crewman to economically provide on-orbit servicing. Attachment of crewman mobility aids and worksite provisions must be considered in the early RMS development phase.

5.1.8 Handhold-to-Spacelab Attachment

The exterior skin of Spacelabs (and Free-Flying Automated Payloads) may be ribbed structures. Portable mobility aid attachment to the ribbed configuration may be accomplished using an ice-tong arrangement. The concept shown in Figure 5.26 would attach between the hat sections and slightly compress the sections together to maintain a rigid contact. The "spikes" or "teeth" would indent the material to prevent slippage. The unit is adjustable to various lengths and is actuated by an over-center lever device.

5.1.9 MMU Translation System

The capabilities of the proposed Manned Maneuvering Unit (MMU) were reviewed in conjunction with the Shuttle Orbiter subsystems and payloads for practicable MMU applications. A number of applications were identified which have the potential of reducing the Orbiter attitude maneuvering expendables and accessing the payloads and the Orbiter exterior areas which otherwise would be unattainable. The general types of tasks performed by an EVA crewman could be performed from the MMU with expanded capabilities to service remote satellites (see Figure 5.27). Typical tasks relative to the Orbiter exterior and free-flying payloads may include the following:

- Inspect
- Capture
- Retrieve
- Deploy
- Repair
- Service
- Rescue

The MMU should be considered as a primary crewman and "light" cargo transporting system for application outside the Orbiter payload bay. Restraining the MMU-crewman combination at a worksite is addressed in Section 6.0.

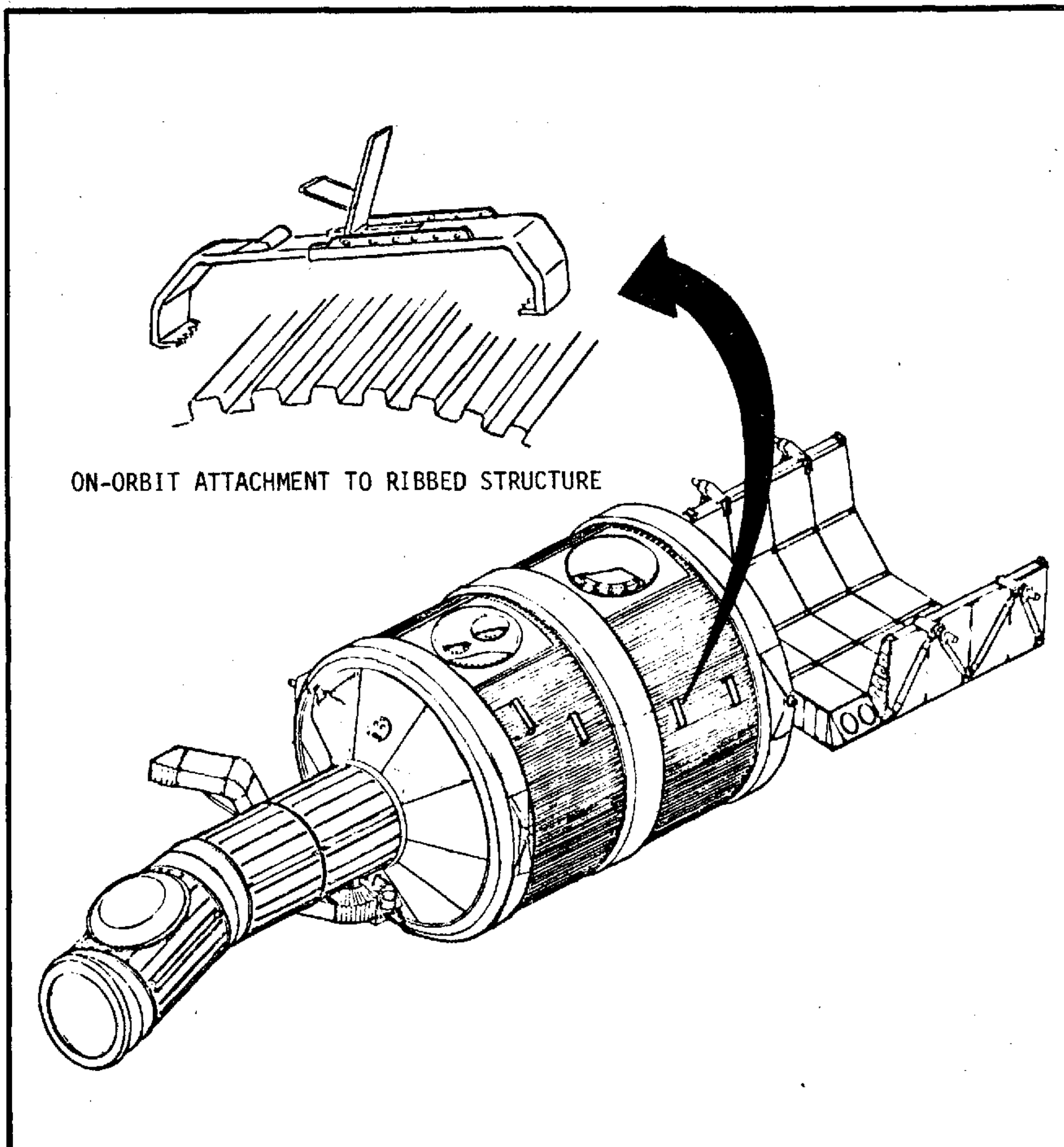
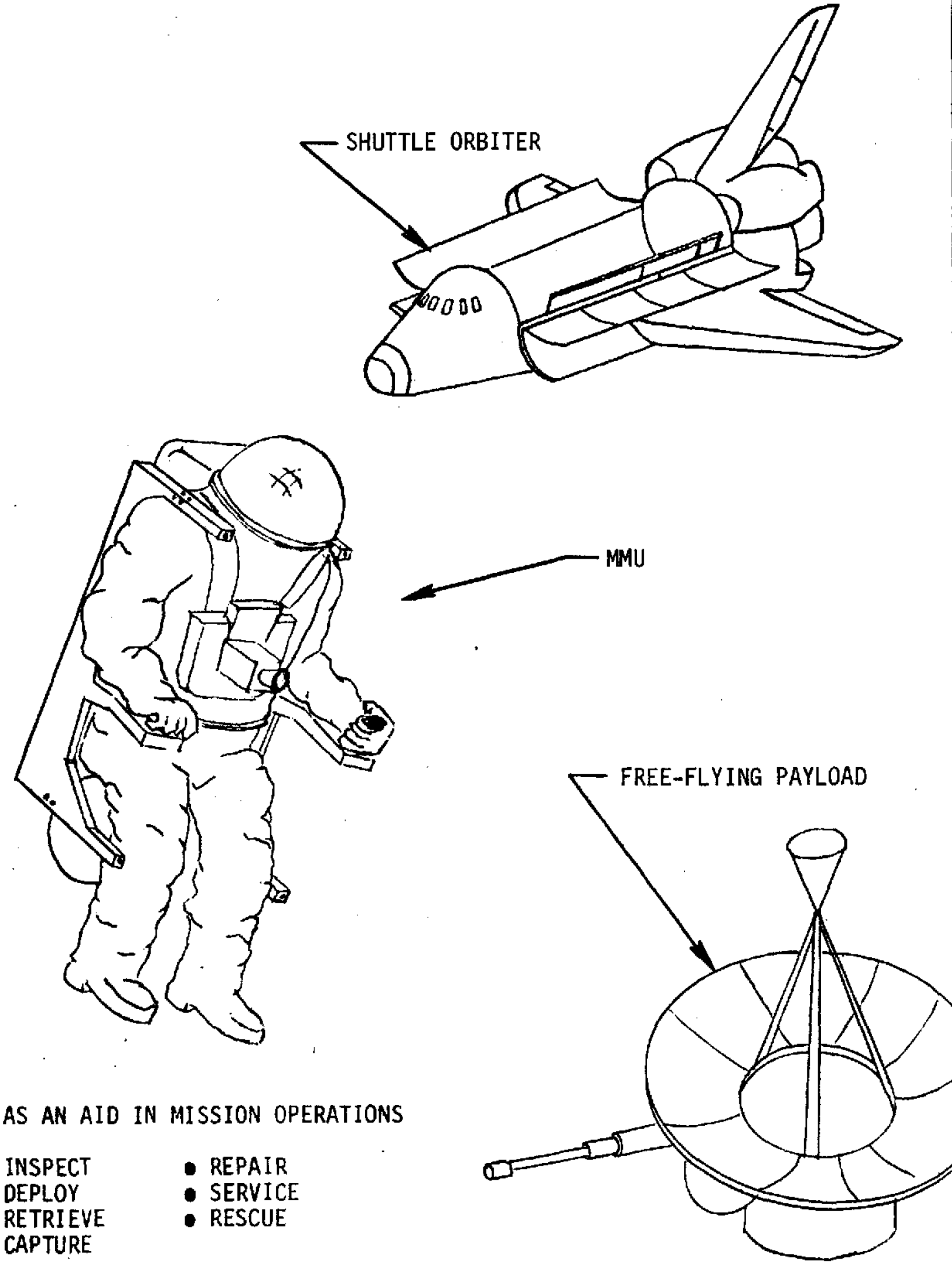


FIGURE 5.26: Ice-Tong Handhold Attachment Concept--Ribbed Structures



MMU AS AN AID IN MISSION OPERATIONS

- INSPECT
- DEPLOY
- RETRIEVE
- CAPTURE
- REPAIR
- SERVICE
- RESCUE

FIGURE 5.27: MMU Candidate Applications

5.2 CREWMAN AND EQUIPMENT TETHERS

The EVA crewmen will be tethered during all external activities except, perhaps, MMU free-flying operations. Tethering the crewman while he translates or performs tasks throughout the payload bay and on payloads extending from the Orbiter may require a number of techniques and equipment items. A review of crewman and equipment tethers used on previous space programs and in industrial/ consumer applications was conducted. The tether systems reviewed included:

- Reel Tether (fixed to vehicle or portable)
  - Mechanical takeup, friction playout
  - Powered takeup, friction playout
- Reel Tether (attached to EMU)
- Wrist Tether
- Waist Tether
- Equipment Tether

A single tether line extending the length of the payload bay may easily become entangled; shorter tethers (two or three) would require frequent positioning and afford a greater potential of loss of contact with the vehicle during the connect/disconnect operations; dual personal tether reels with a cable length of 6-9 m. (20-30 ft.) would require translation to the center of the payload bay and a 9 m. (30 ft.) return trip to disconnect the first tether. The latter concept with one or two intermediate/backtrack operations may be feasible. A personal tether reel concept is shown in Figure 5.28. Other tether concepts considered include: (1) tether trolleys to run on continuous handrails; (2) tether cables running parallel to handrails; and (3) tether lines attached to the RMS (would involve crewman tracking).

The crew and cargo tethering arrangement for Shuttle applications may require tailoring to each EVA mission. A single tether system to effectively accommodate all EVA operations in the payload bay does not appear feasible.

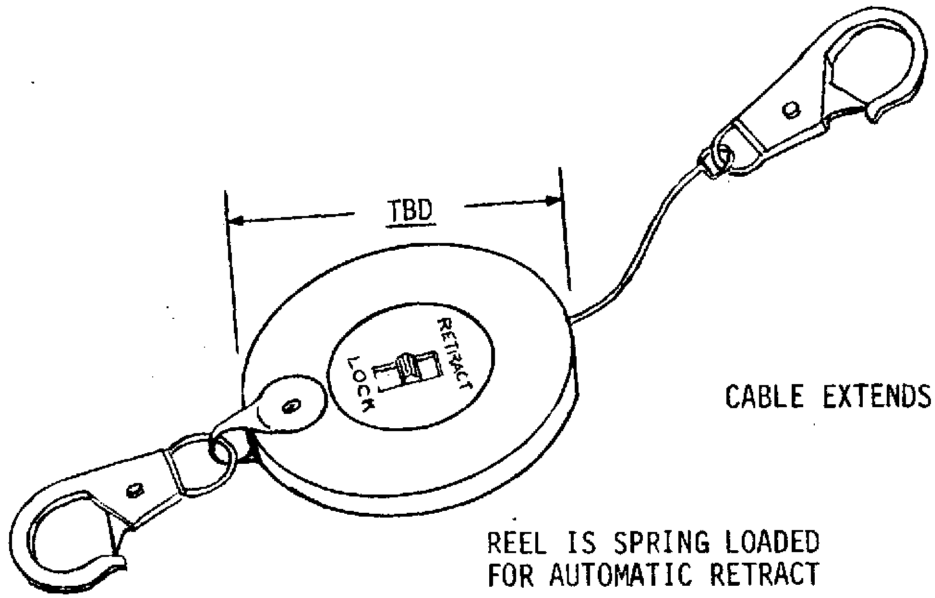


FIGURE 5.28: Portable Retractable Tether

Additional information on crewman and equipment tether devices used on Gemini, Apollo and Skylab Programs are contained in Volume I, Section 1.1 of this study.

5.3 CARGO TRANSFER CONCEPTS

With a high-density payload bay experiment arrangement, a simple straight transfer of equipment/cargo to points in the bay may not be possible. This may necessitate the use of manual cargo transfer over various structural configurations, remote manipulator systems for cargo handling assistance and portable clothesline systems or extendible booms installed between the worksite and equipment stowage areas. Several concepts are considered in the following subsections.

5.3.1 Manual Cargo Transfer

The manual hand-carry concept is the simplest and least costly means of equipment/cargo transfer. An EVA crewman can translate over and around payloads/equipment that is not feasible for a mechanical system. However, several factors must be considered: (1) the cargo package must be tethered to the EVA crewman to allow complete hand and body movement; and (2) the mass and size of the cargo/package must be limited to ensure crewman and equipment safety during transfer. During manual cargo transfer on previous EVA missions, the equipment being transported was attached by wrist and waist tethers to the crewman.

5.3.2 RMS Cargo Transfer

Depending on the intricate tasks involved, RMS video coverage, time constraints, cargo mass, payload arrangement, etc., the Orbiter Remote Manipulator System may provide an additional dimension to Shuttle cargo handling. The RMS-crewman combination may satisfy the majority of Orbiter payload bay cargo transfer requirements.

Figure 5.29 depicts an RMS delivering equipment to the EVA crewman. Depending on the RMS control and video systems selected for Shuttle application, the EVA crewman may operate the unit using an external hand controller that provides inputs to the control unit at the payload specialist's station (PSS). The EVA crewman would control the RMS only within his field-of-view. Control assistance would be provided from the PSS for out-of-view operations.

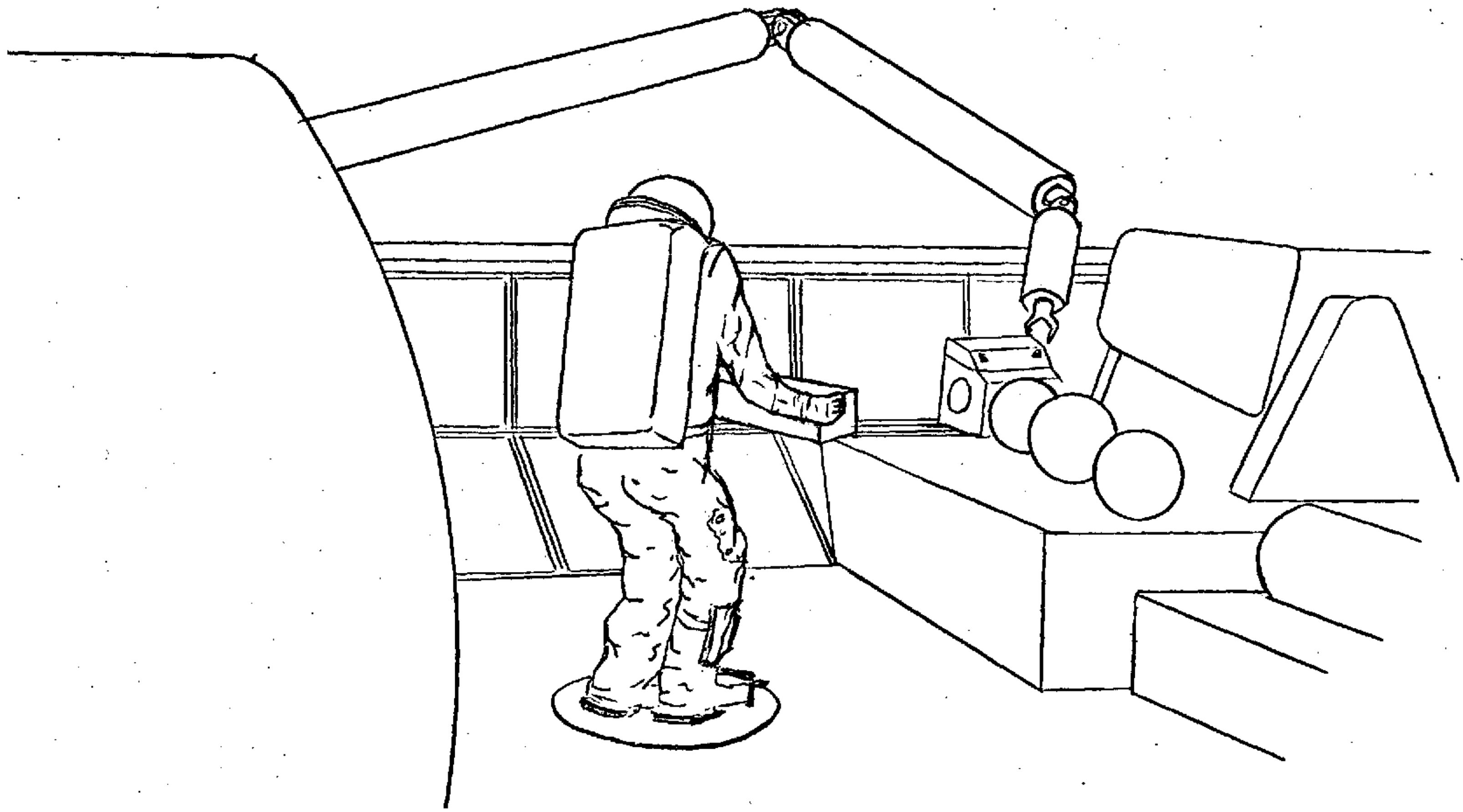
5.3.3 Extendible Boom Cargo Transfer

Extendible booms were used during the Skylab EVA missions to transport solar astronomy data between external worksites. A review of the Skylab boom system and space applicable units was conducted relative to the Shuttle Program. Figure 5.30 depicts a portable boom mounting system for use in the payload bay. The system could be mounted at various locations within the payload bay, on payload structures, pallets, etc. Units more compact than those used on the Skylab Program are recommended.

5.3.4 Clothesline Cargo Transfer

If a straight line transfer path is available between the worksite and the equipment stowage areas, a manual clothesline system, which was used on Skylab as a backup to the extendible booms, may be used for cargo transfer.

A motorized concept could also be developed. The system would consist of an electrically driven "hoist" arrangement, 55 m. (180 ft.) of small diameter cable with an equipment hook fixed to the clothesline, and the appropriate switching/control system. The concept as currently visualized would be a portable unit, readily connected at the worksite and utilizing Shuttle Orbiter power. The operational characteristics are summarized in Figure 5.31.



CARGO TRANSFER BY REMOTE MANIPULATOR SYSTEM:

- CONTROLLED BY EVA CREWMAN AT EXTERNAL WORKSITE
- ASSISTED BY PAYLOAD SPECIALIST AT PSS

FIGURE 5.29: RMS Cargo Transfer Assist Mode

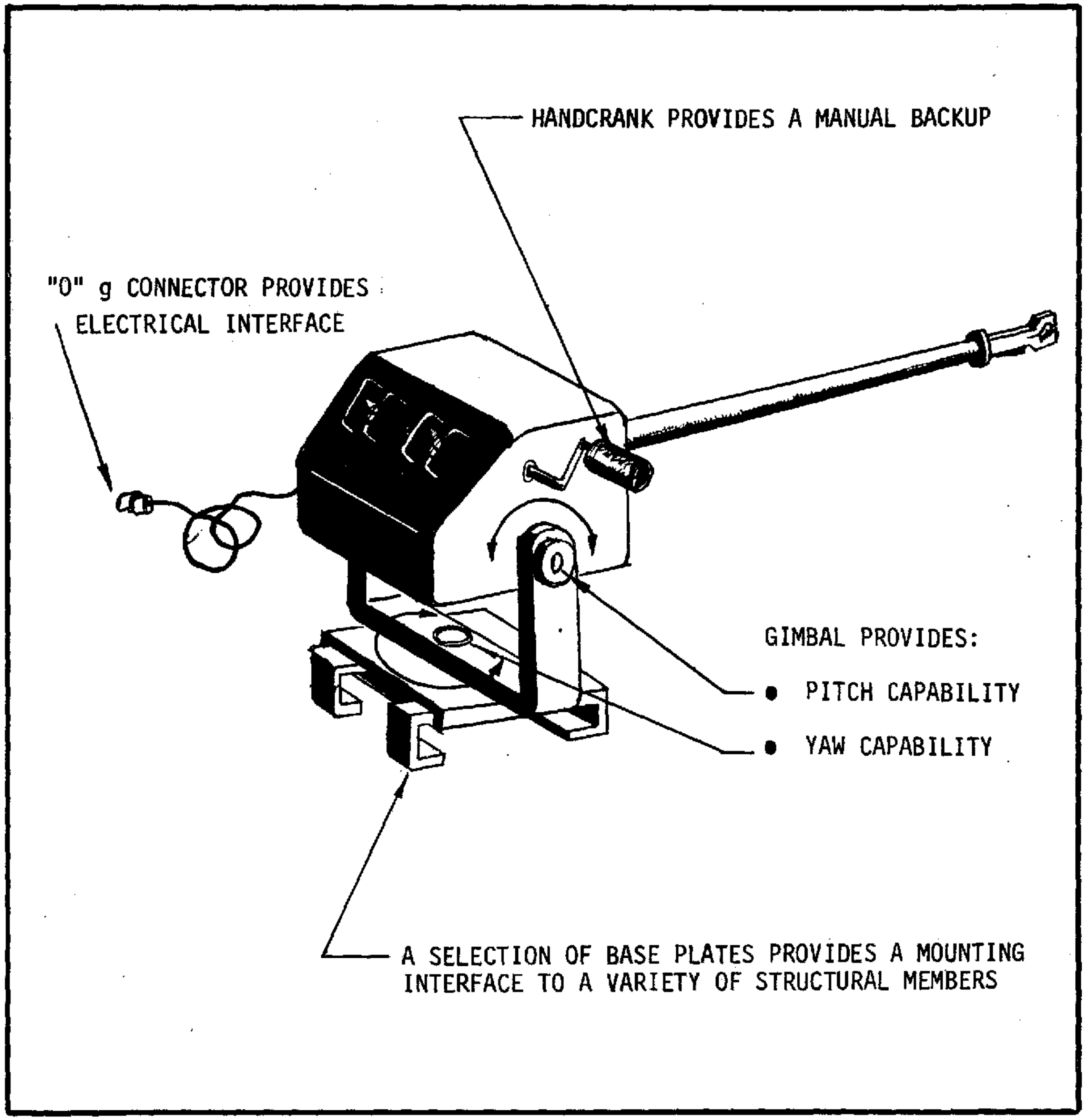


FIGURE 5.30: Cargo Transfer Boom--Gimbal-Mounted Concept

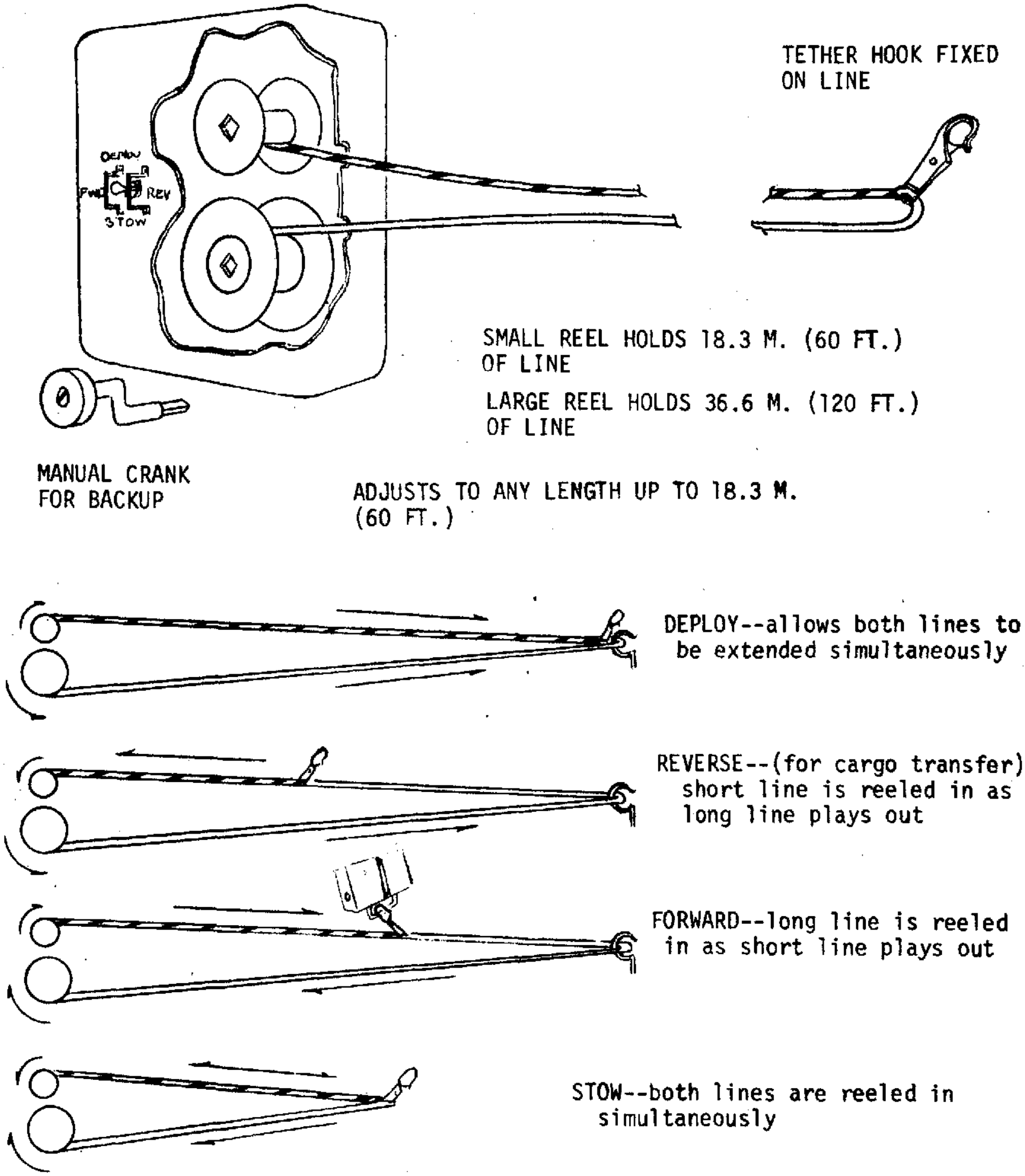


FIGURE 5.31: Adjustable Clothesline Concept--Motorized

The development of the multimission Space Shuttle vehicles and the increased number of planned/potential Orbiter and payload EVA tasks will require more versatile worksite provisions than the fixed dedicated workstations of previous space programs. An EVA workstation system to support diversified future programs will be required to accommodate a wide variety of EVA maintenance, servicing, and repair operations and also interface with numerous payload and vehicle structures. Several important aspects of EVA worksite provisions were evidenced during the Gemini, Apollo and Skylab Programs. Major design considerations include:

- Adequate worksite restraints are mandatory for EVA operations.
- Foot restraints used on the Skylab Program are fully satisfactory.
- Ingress/egress aids (e.g., handholds, handrails, structures) are required for foot restraint ingress/egress.
- All tools and cargo handled at a worksite must be tethered (unless the cargo is being repositioned from one stowage location to another at the worksite).
- All cargo must be tethered when transferred from worksite to worksite.
- Temporary stowage provisions for "loose" articles handled at the worksites are an asset to task performance.

The development of portable-module EVA workstation concepts and their interface to orbital elements is aimed toward reducing the design and development cost to each payload and Shuttle mission. An encouragement for planners to design payloads and Orbiter subsystems to accommodate on-orbit EVA servicing, by providing off-the-shelf EVA support hardware, is also a consideration.

Attempts were made to develop concepts for a "universal" workstation/foot restraint attachment device based on available Orbiter and payload candidate interfaces. However, details of the interfaces were not sufficient to define

a representative set of design requirements. When the EVA crewman interfaces are defined, the quantity of different configurations may prohibit design of a "universal" attachment within on-orbit weight, size and transportability limitations. The universal concept of providing portable EVA workstations should be pursued when sufficient interface data becomes available.

Several concepts for attaching portable EVA workstations are provided ranging from passive receptacles at the worksite to a standard receptacle mounted on the workstation. The workstation standard receptacle would accept various "dedicated" inserts to interface with payload and Orbiter hardware. Since passive workstation receptacles located only at planned EVA worksites cannot support all contingency EVAs, present concept development activity is centered around developing a common receptacle/connector integral with the portable workstation receptacle and a "set" of fixtures to interface with the various payload and Orbiter structural configurations. Each fixture would interface with the workstation receptacle and to a specific or perhaps several structural configurations.

The EVA foot restraint hardware used on the Skylab Program is considered applicable to the Space Shuttle. Numerous configurations for mounting the principal restraint components (i.e., toe and heel fixtures) can be conceived. The workstation concepts developed in the following subsections utilize two basic mounting plates--a tripod arrangement and a rectangular honeycomb plate.

6.1 TRIPOD PORTABLE EVA WORKSTATION

The tripod foot restraint concept shown in Figure 6.1 represents a system for attachment at planned worksites with standard three hole attachment provisions or for use with special adapter units such as adhesive pad attachments. The foot restraint plate may be affixed to the foot restraint adapter with bolts, pip-pins, quick connect/disconnect fasteners, etc. A rotating foot restraint may be incorporated by using quick connect/disconnect fasteners. Provisions such as portable lights, tool kits, module stowage, cameras, etc. may be integrated into the workstation as required by specific tasks. The basic tripod EVA foot restraint concept is shown expanded into a modular workstation in Figure 6.2.

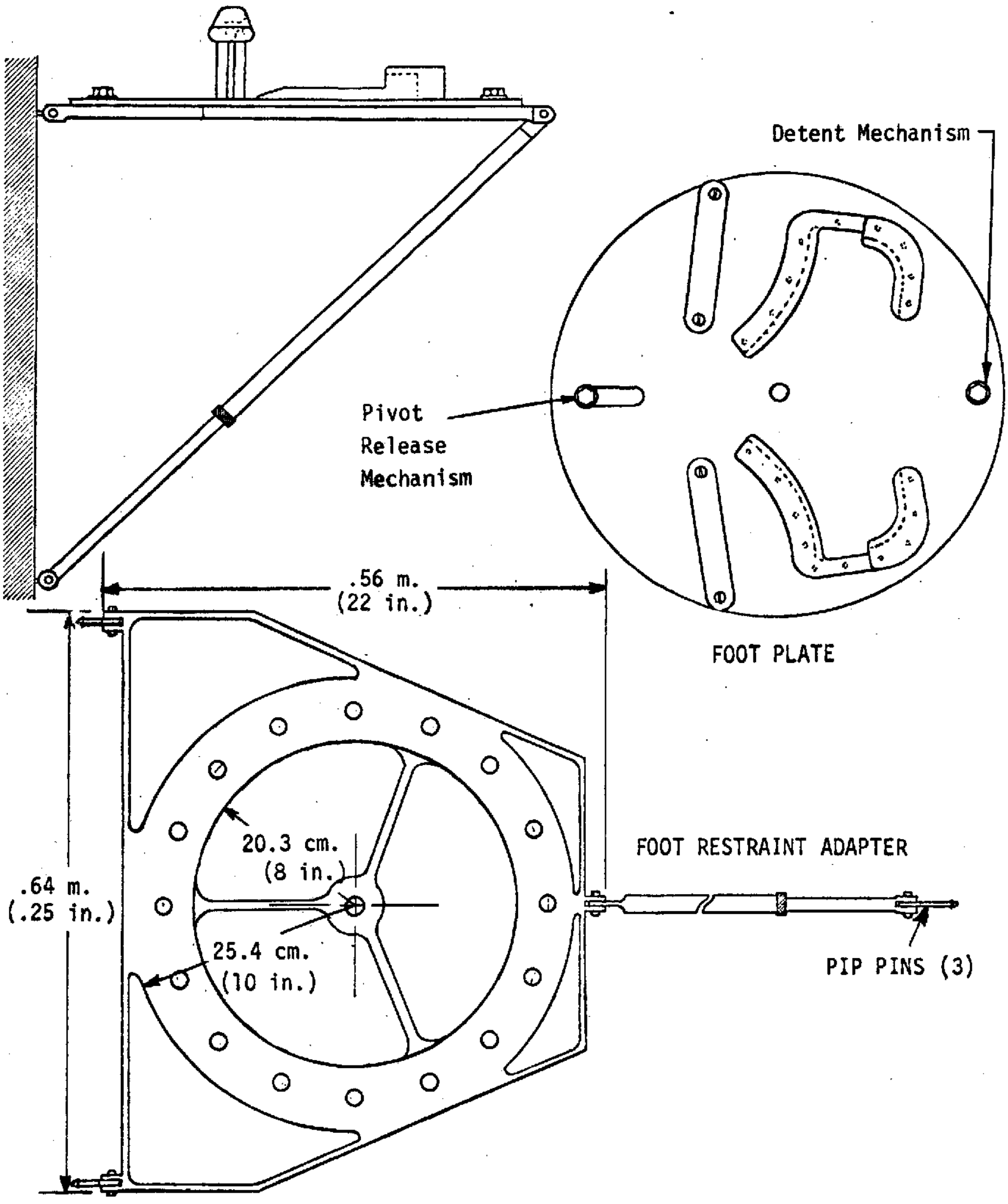


FIGURE 6.1: Basic Tripod Foot Restraint Concept

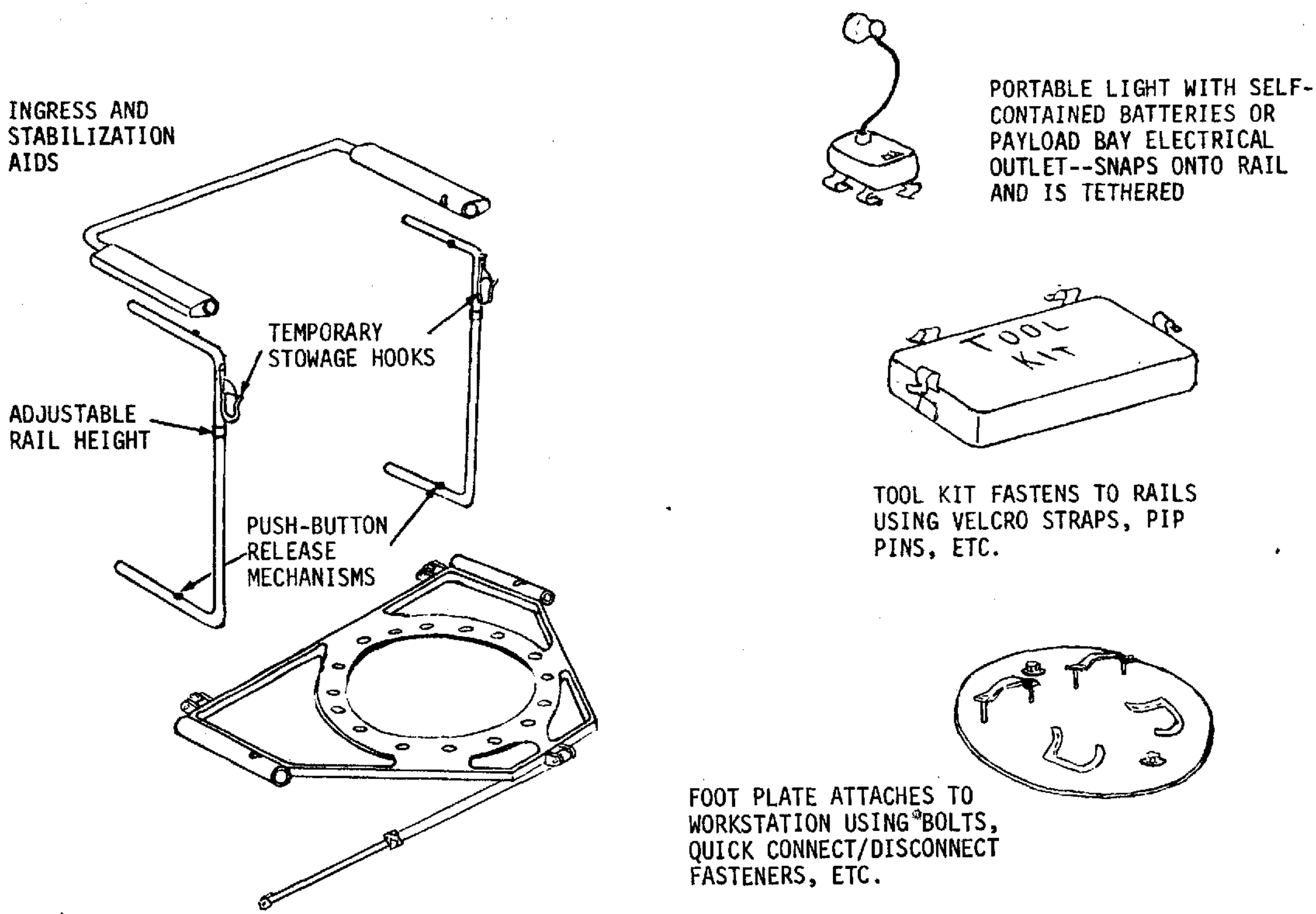


FIGURE 6.2: Tripod Workstation--Modular Concept

A folding sequence for stowing the tripod workstation with a cross-bar ingress aid arrangement is shown in Figure 6.3 The workstation can be configured at the stowage area and folded for transporting to the worksite by the EVA crewman or Shuttle RMS. Attaching the workstation to a three hole pattern can be accomplished at 120° intervals for three orientations. The rear support member allows the workstation to be adjusted in the pitch axis. The circular hole pattern provides yaw positioning.

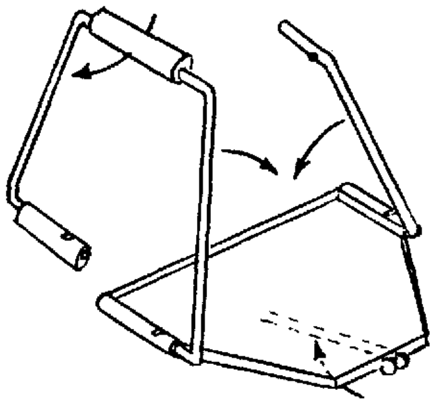
6.2 BASIC INTEGRATED EVA WORKSTATION

The EVA workstation concept shown in Figure 6.4 provides only the necessary equipment to allow crewman ingress/egress and restraint at the worksite. The workstation would be used at worksites that provide additional (integrated) EVA support equipment or provisions to attach portable handholds, cargo stowage hooks, lights, etc. The basic workstation as shown in Figure 6.4 could be used for inspection and monitoring tasks and tasks requiring light to medium force applications.

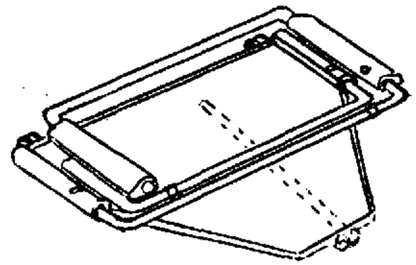
Attachment of the workstation would require receptacles mounted at the worksite or an additional adapter plate. The base plate pivots 360° and adjusts 90°+ in the pitch axis. A ball and socket device is depicted for attaching the system to the worksite interface. The handrail folds for stowage and provides a handhold for transporting.

6.3 FLAT PLATE EVA WORKSTATION

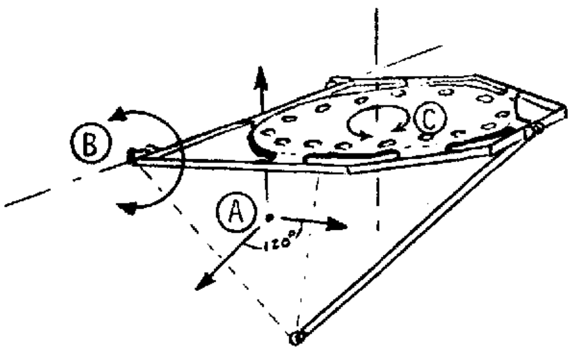
The basic portable workstation concept was developed on a previous URS/Matrix contract. A modular approach to the concept is shown in Figure 6.5. The configuration provides most of the elements needed by the crewman for performing the Shuttle EVA tasks identified to date (mid-1974). As a modular unit, the foot restraints only may be utilized or the basic unit configured into a full workstation with ancillary support equipment modules. An ingress aid may be attached to the basic foot plate. The ingress aid incorporates a temporary package stowage hook, handhold and tether clip. Tool kits, lights, cameras and various supporting hardware can be attached to the ingress aid.



FOLDING SEQUENCE (RAILS MAY ALSO BE REMOVED)



STOWED CONFIGURATION



Ⓐ EQUIDISTANT HOLES ON MOUNTING SURFACE ALLOW 3 WORKSTATION ORIENTATIONS 120° APART

Ⓑ REAR SUPPORT MEMBER ALLOWS WORKSTATION ADJUSTMENT IN PITCH

Ⓒ CIRCULAR HOLE PATTERN ALLOWS DISCRETE YAW POSITIONING OF WORKSTATION

FIGURE 6.3: Tripod Workstation/Stowage Folding Sequence

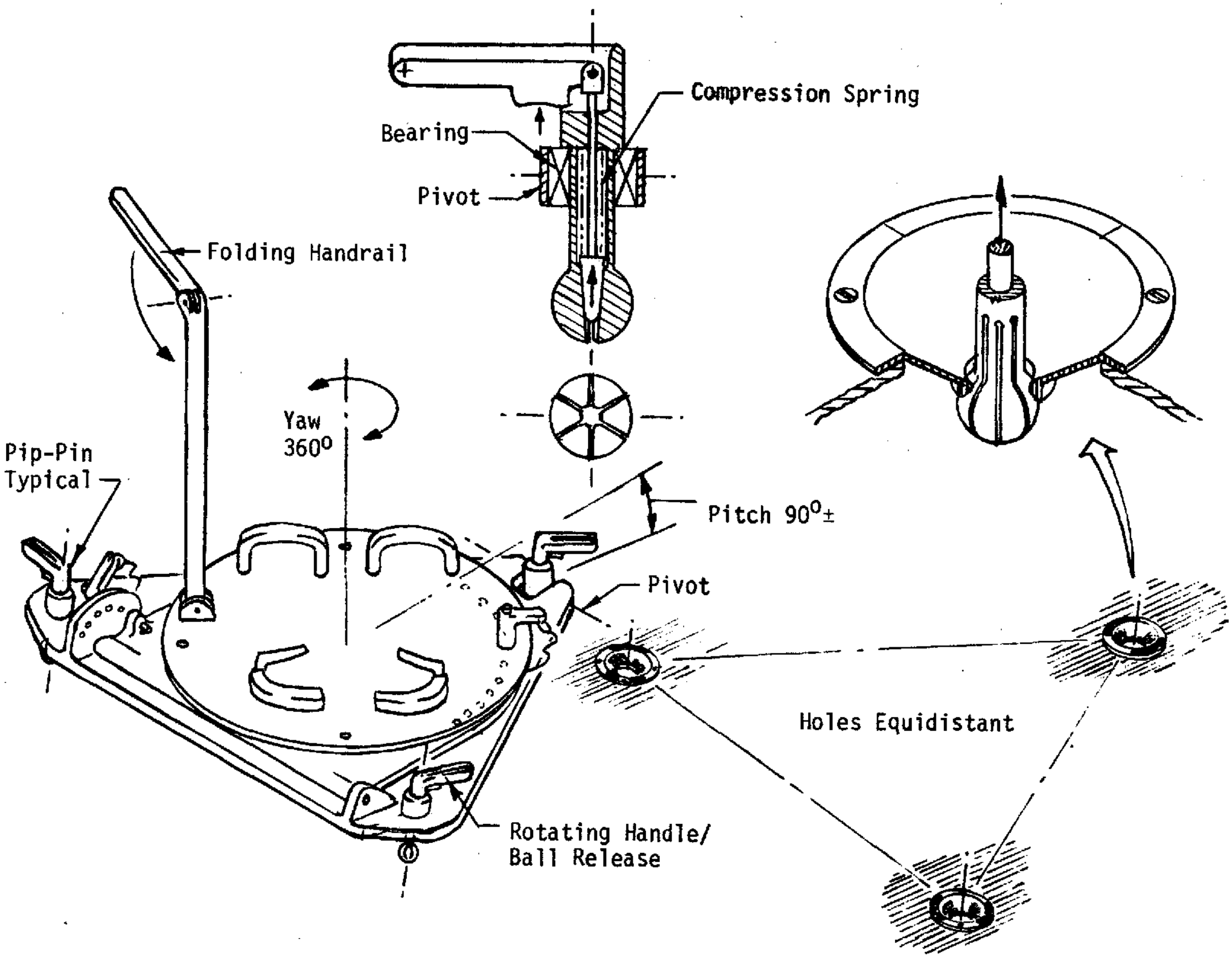


FIGURE 6.4: Basic Integrated EVA Workstation Concept

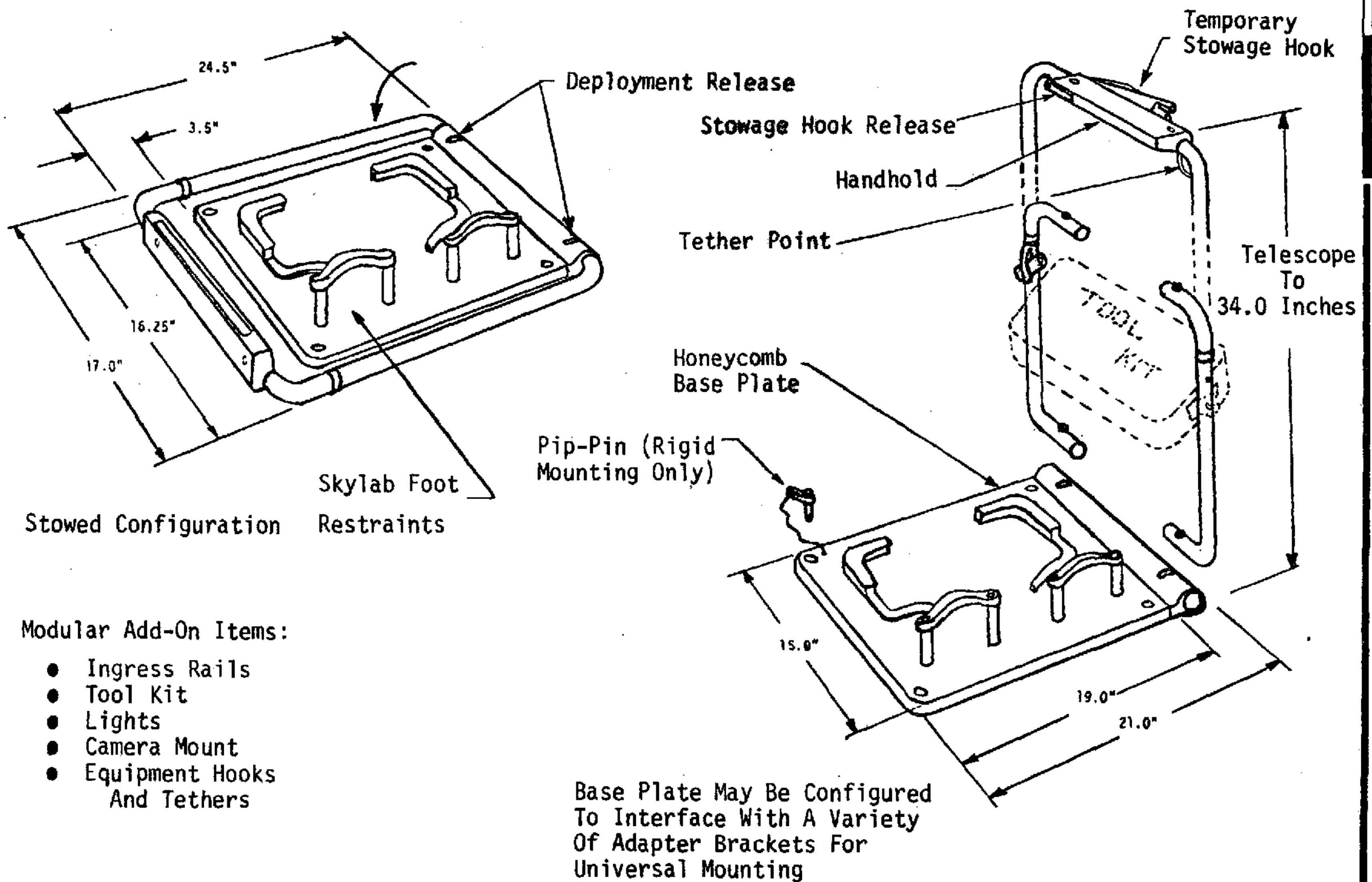


FIGURE 6.5: Flat Plate EVA Workstation Concept

The primary concept development area for the flat plate workstation is one of designing an attachment system for interfacing the workstation to a variety of payload and Orbiter configurations. Concepts are depicted in Subsection 6.5.

6.4 WORKSTATION/COMPONENT WEIGHTS

Preliminary weight calculations are provided in Table 6-1 for the workstation concepts developed. The weight of each major workstation component is provided to allow the experiment planner to estimate total weight based on each specific EVA mission.

6.5 EVA WORKSTATION INTEGRATION

The review/analysis of the Orbiter subsystems and candidate payload interfaces relative to EVA hardware attachment interfaces has indicated a number of standard structural configurations may be available. These standard structural/surface configurations include:

- Round Bar/Tubular Trusses
- Flat Surfaces
- Ribbed Structures
- Handrails (Oval Sections)
- Square Bars
- Angles/Plates
- Tee Sections
- Thermal Protection System

Since payload interfaces requiring EVA support systems attachment are relatively undefined, the attachment concepts are primarily based on the standard configurations.

6.5.1 Angle/Plate Workstation Attachment Concept

A concept for attaching EVA workstations to a square bar, an angle, or a flat protruding surface is shown in Figure 6-6. The serrated teeth approximately .08 cm. (.030 in.) would form indentations in the structural member to prevent slippage. The unit would be positioned and hand-tightened by the crewman and secured by standard hand tools.

TABLE 6-1: Workstation Component Weights

COMPONENT \ WORKSTATION	FLAT PLATE		TRIPOD		BASIC	
	kg	(lb)	kg	(lb)	kg	(lb)
FOOT PLATE	2.5	5.5	2.3	5.0	3.0	6.5
INGRESS RAILS						
• ONE SIDE	2.0	4.5	2.0	4.5	1.0	2.5
• SEMI-CIRCULAR	--	--	4.0	9.0	--	--
STOWAGE HOOK/ TETHER RESTRAINT	.5	1.0	.5	1.0	--	--
TOOL KIT - EMPTY	2.0	4.5	2.0	4.5	--	--
LIGHTS	1.4	3.0	1.4	3.0	--	--
FOOT RESTRAINT ADAPTER	--	--	1.8	4.0	2.5	5.5
ADAPTER PACKAGE	1.8	4.0	--	--	1.0	2.5
TOTAL	10.2	(22.5)	10.0*	(22.0)*	7.5	(17)

*Assumes an ingress rail on one side only

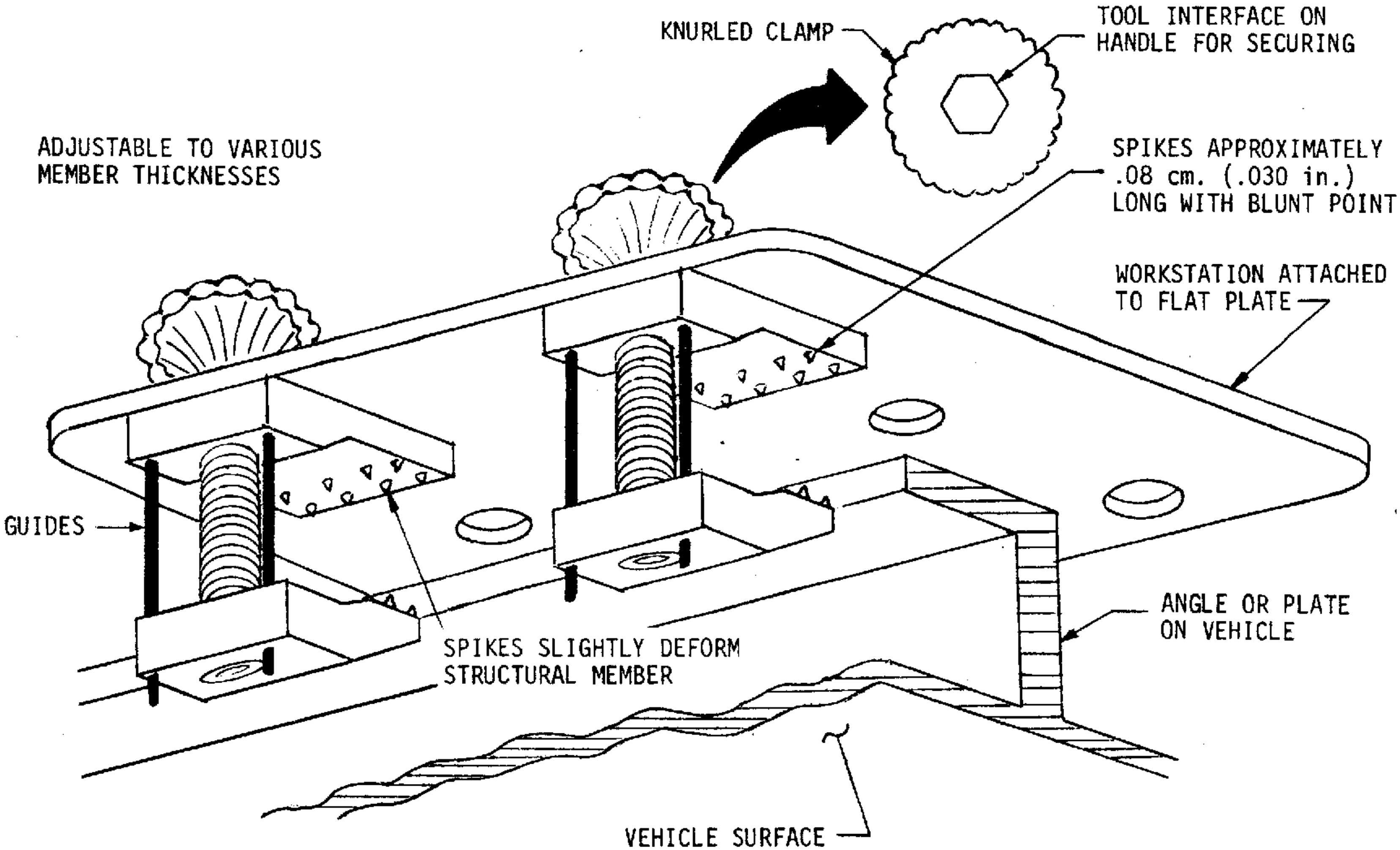


FIGURE 6.6: Workstation to Angle/Plate Attachment Concept

6.5.2 Universal "C" Clamp Attachment Device

The concept shown in Figure 6.7 may be used for attaching an EVA workstation to various structural members. The device would feature removable inserts for attaching to the standard structural interfaces. The "C" clamp device can be fabricated in sizes to interface with a wide range (i.e., size) of structures. Figure 6.8 depicts an adapter for attaching the "C" clamp device to a portable workstation. The adapter would consist of a special ball and socket design to allow positioning by the crewman and securing by using hand tools. The adapter bolts to the workstation and allows discrete positioning in the "yaw" plane. The ball joint allows additional positioning.

6.5.3 Adhesive "Pad" Workstation Attachment

An adhesive pad for attaching the tripod or basic workstations (concepts) to the Orbiter Thermal Protection System (TPS) or any flat surface is shown in Figure 6.9. A thin aluminum plate backed with a semi-flexible pad and an adhesive, which would be exposed by removing a protective cover, could be applied to the flat worksite. The fittings on the pad would accommodate the connectors on the EVA workstation. The adhesive could remain on the mounting surface when the attachment is removed for payload application. A solvent could be used to remove the adhesive from the Orbiter TPS prior to reentry. Additional concept information is shown in Figure 6.9.

6.5.4 Adhesive Disc Workstation

The concept shown in Figure 6.10 depicts adhesive discs for attaching EVA workstation handholds or handrails to the Orbiter TPS or any flat vehicle/payload surface. The adhesive pads incorporate a socket-type interface for the expendable ball attachment devices. The semi-rigid adhesive pads in the triangular arrangement will compensate for slight surface discontinuity and/or curved surfaces. If the restraint pads can remain on the surface after the EVA mission, the workstation only can be removed and returned to stowage. If the restraint pads are adhered to the Orbiter TPS, both the adhesive pads/fixtures

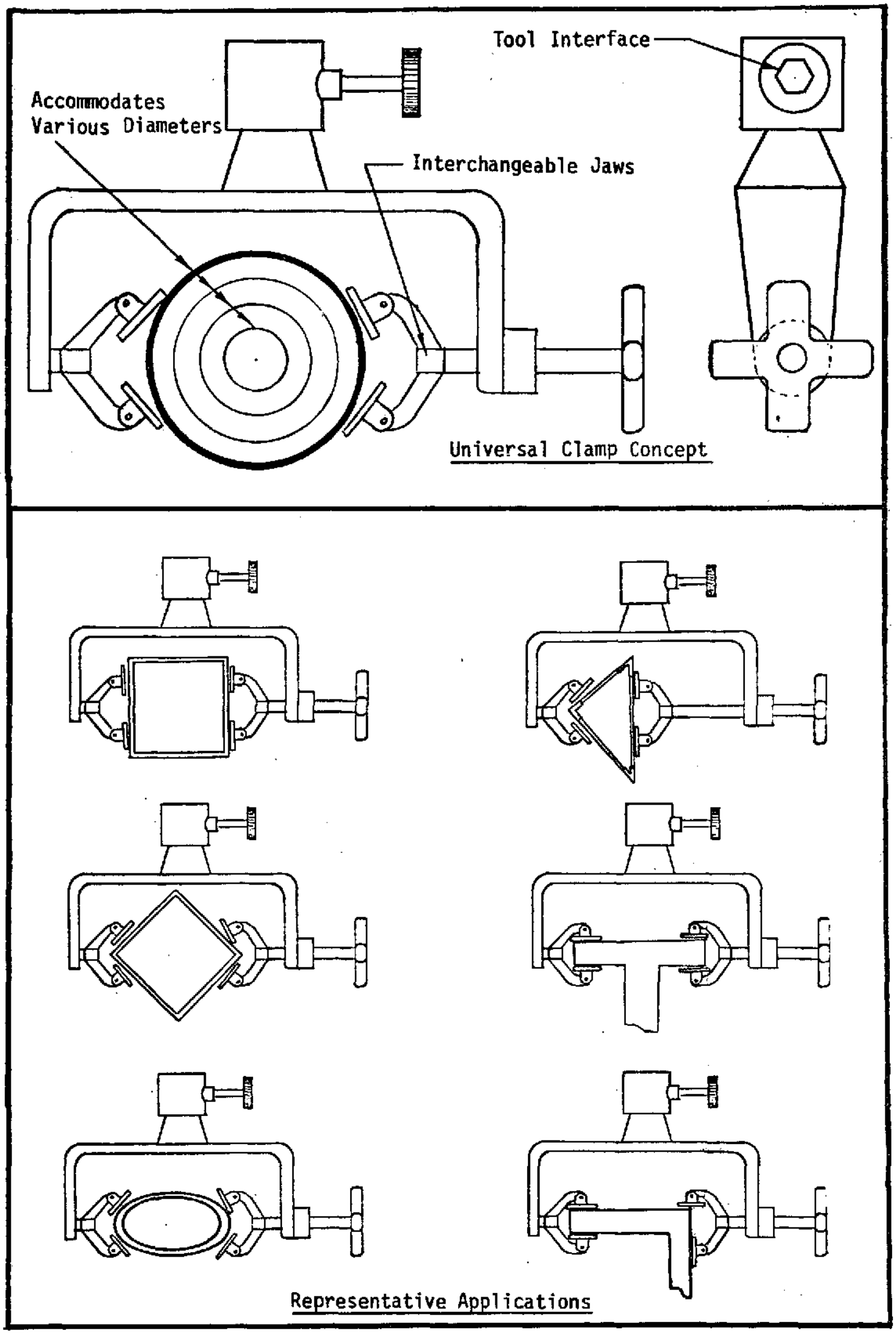


FIGURE 6.7: Universal "C" Clamp Attachment Device

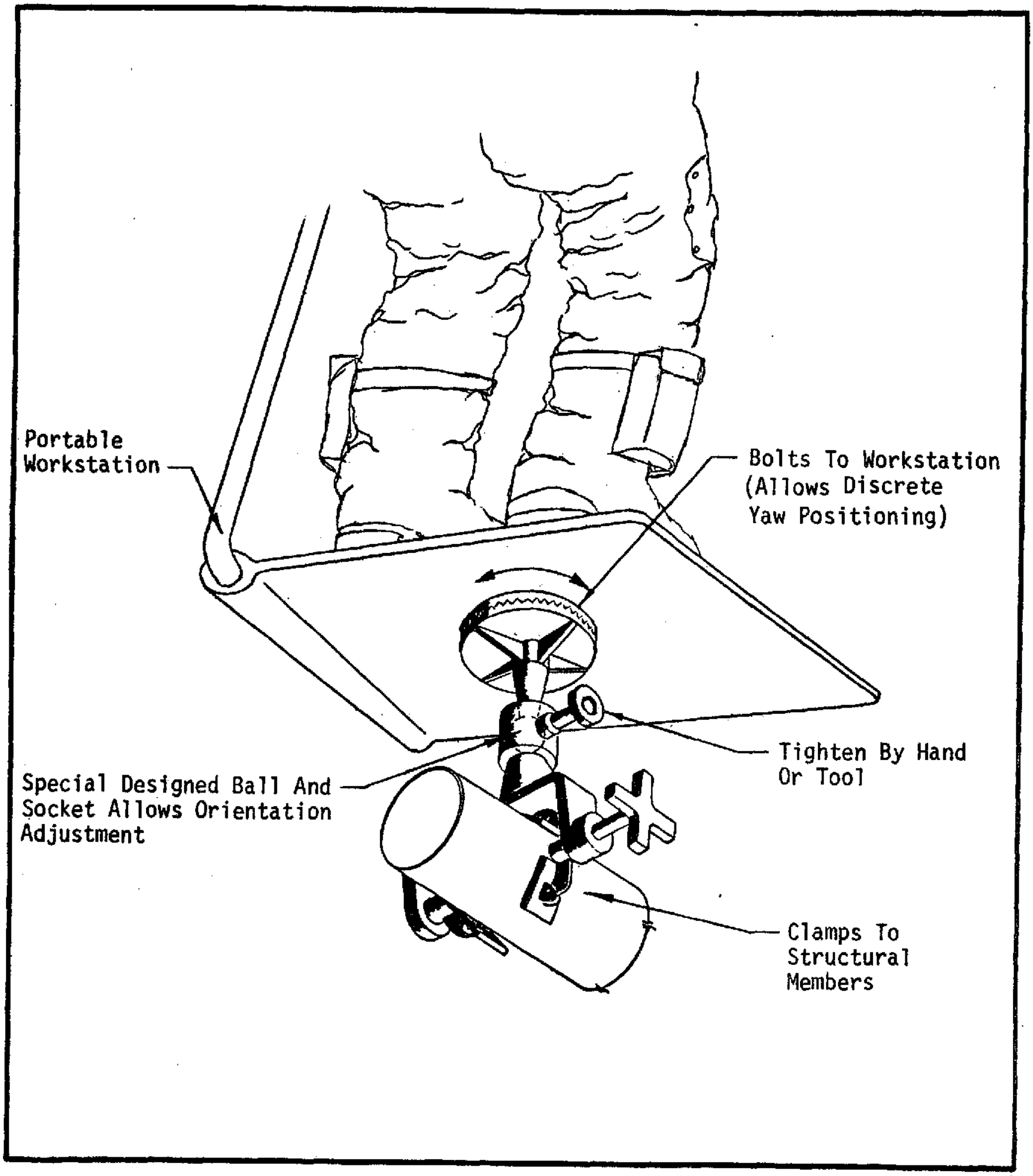


FIGURE 6.8: Universal Clamp to Portable Workstation Interface

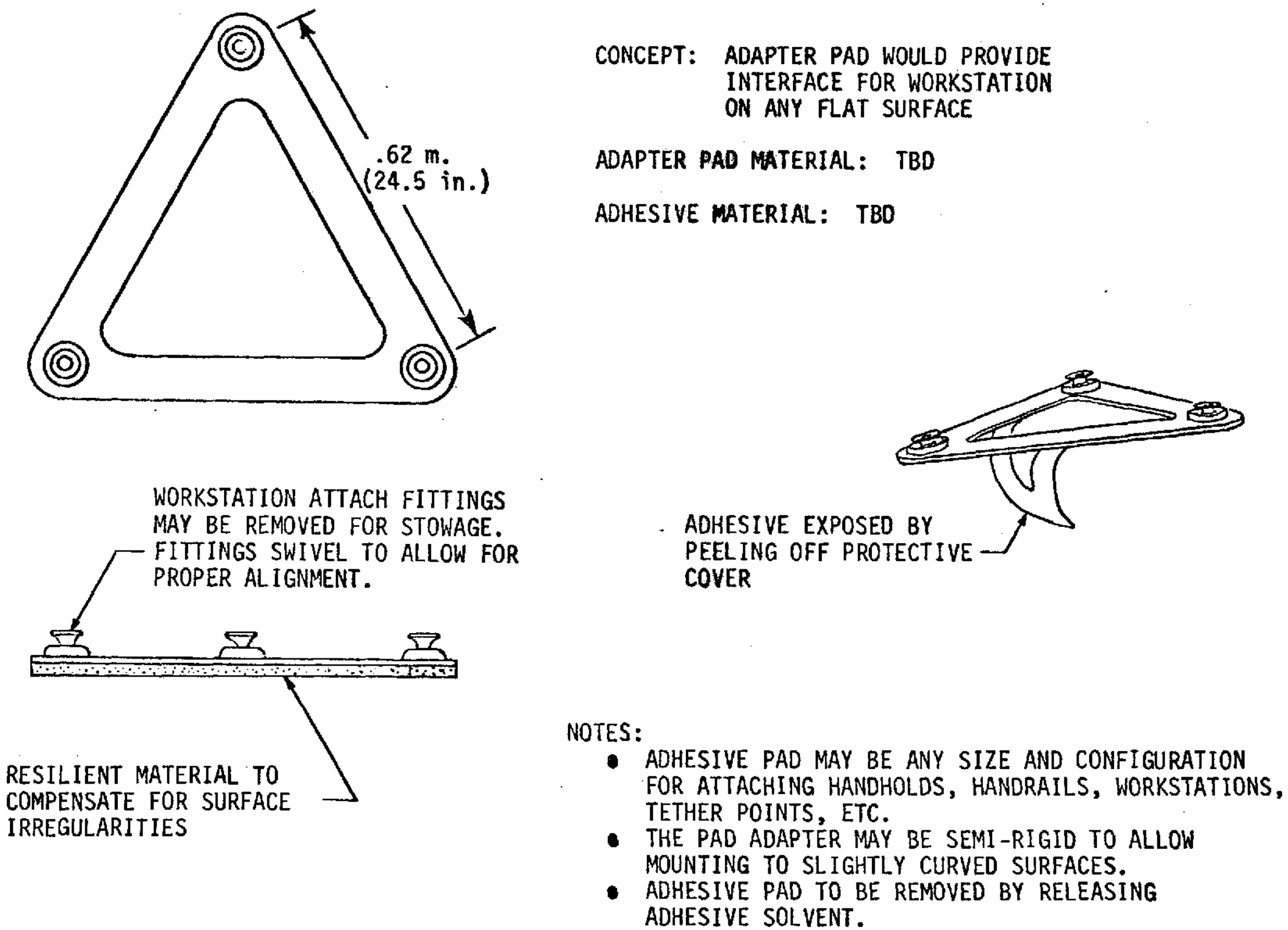


FIGURE 6.9: Adhesive Pad Workstation Attachment Concept

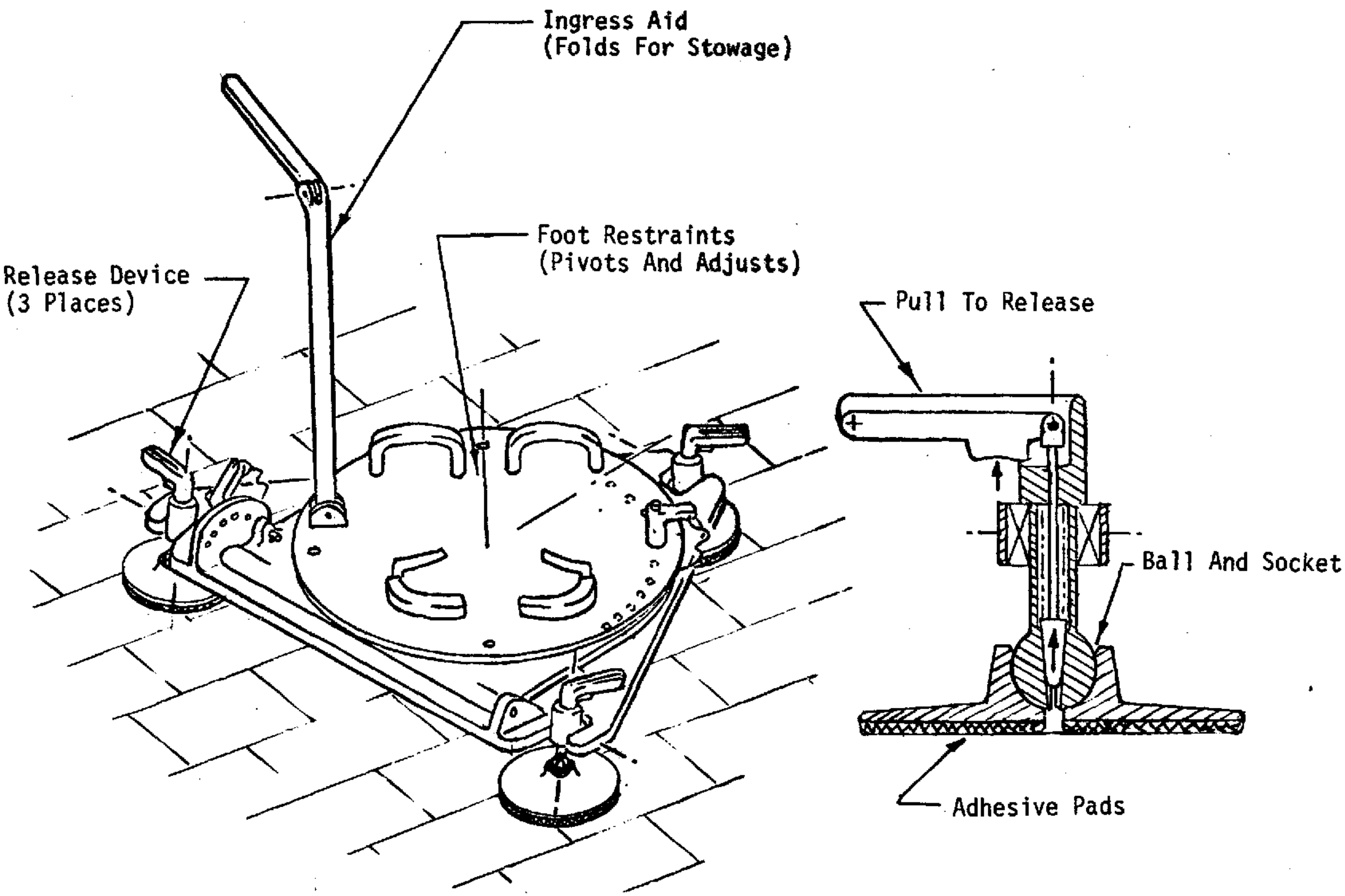


FIGURE 6.10: Adhesive Disc Workstation/Mobility Aid Attachment Concept

and remaining adhesive must be removed (requires detailed study to determine the amount of adhesive residue allowed to remain on each Orbiter TPS surface). The size of the adhesive pads may vary depending on the force application required at the specific worksite. Each 10 cm. (≈4 in.) diameter adhesive pad with a bonding strength of .4 kg/cm^2 (≈6 lb/in^2) will provide approximately 35 kg. (75 lbs.) reactive force.

A typical application of an EVA workstation adhesive pad (or discs) attached to the tripod foot restraint (concept) is shown in Figure 6.11. The MMU would be required to station-keep in order to apply the adhesive pad and connect the workstation.

6.6 ORBITER EXTERIOR EVA HARDWARE ATTACH POINTS

A number of potential workstation attachment locations on the Orbiter exterior (in addition to the TPS) have been identified. These locations are listed in Table 6-2 and include areas over most of the Orbiter vehicle. Some attachment locations will provide access to only limited areas, such as the Orbiter side access panels while attachment to the TPS would provide access to most external surfaces. However, attaching to the TPS may limit the amount of force that an EVA crewman could apply at a worksite since the surface of the TPS tiles is fragile.

Numerous methods/techniques for attaching the workstations to the Orbiter exterior have been considered (reference Table 6-2). Several techniques have been eliminated due to safety aspects or damage to the TPS. The electroadhesors (if developed) could only be applied to limited areas since the TPS is non-conductive. Chemical adhesives and mechanical devices appear to be more applicable. EVA hardware attachment to most of the interfaces listed in Table 6-2 are self-explanatory. However, the EVA interface concept to the Orbiter access panels is summarized in the following subsection.

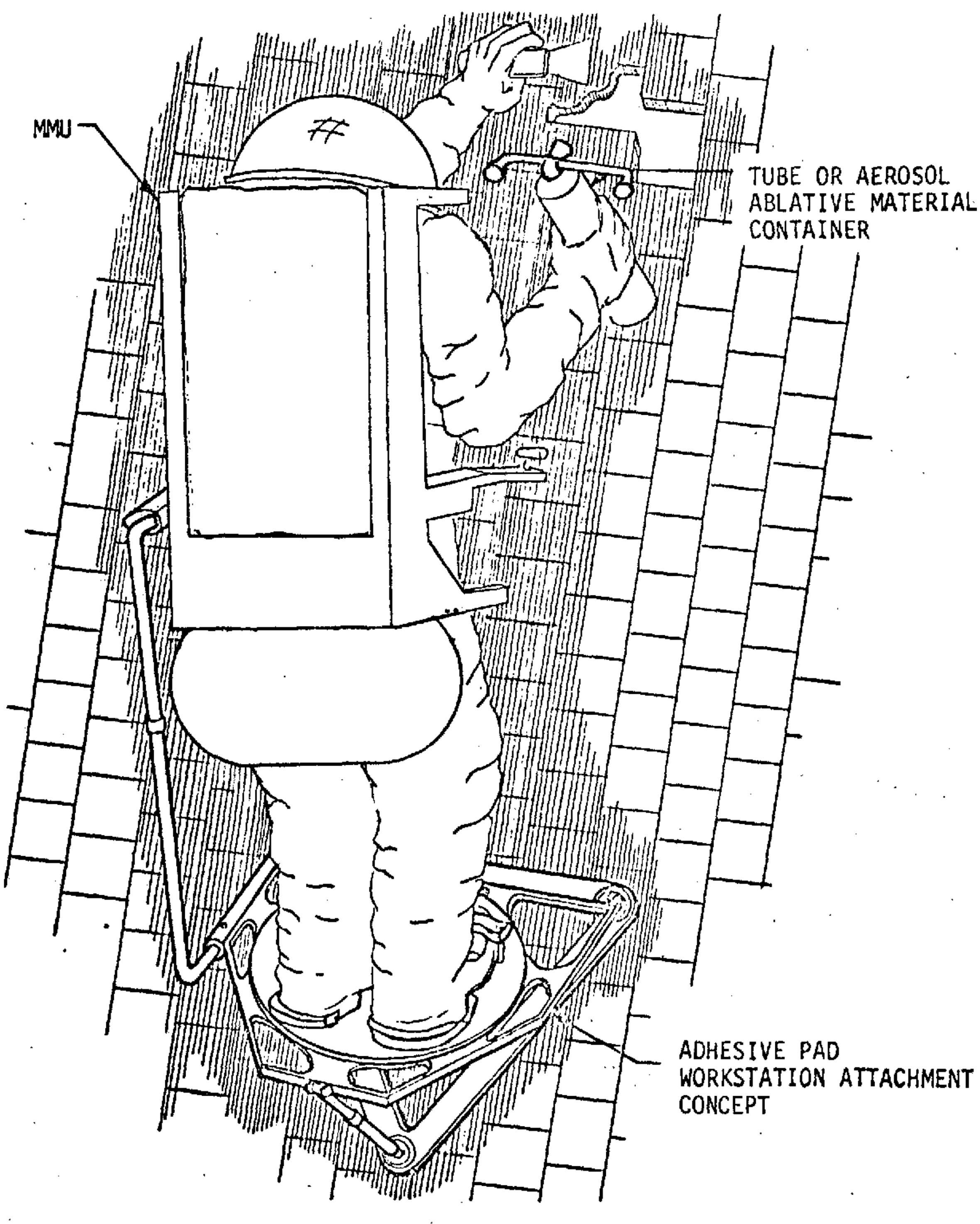


FIGURE 6.11: TPS Repair from Workstation

TABLE 6-2: Candidate Orbiter Exterior EVA Support Hardware Attach Points

- TPS "Flat" Surface (TPS covers approximately 95% of vehicle)
  - use chemical adhesive pad
- Access Panel Retainer Bolts/Plugs
  - remove plugs, attach restraint device in threaded receptacle
- Side Hatch--Penetration in TPS for Restraint Attachment
  - side hatch ingress/egress
- RCS Thrusters
  - insert expandable plug into thruster nozzle for restraint
- Edges of Flat Structural Members (doors, door facings, legs of angles, etc.)
  - use a C-clamp device
- Round Structural Members (wheel struts, door mechanisms, main engine truss)
  - attach universal C-clamp
- Provide Special Attachment Inside Orbiter External Doors (RCS, star tracker, external tank, launch umbilical, etc.)
  - provide receptacle for workstation/restraint attachment

ATTACHMENT TECHNIQUES CONSIDERED

- Tension Device Between RCS Tiles
- Fixed Mechanical Devices
- Chemical Adhesive
- Pyrotechnic Grappler Device
- RCS Nozzle Expandable Plugs
- Electroadhesors

6.6.1 EVA Equipment to Vehicle Access Panel Attachment

Several ground support access panels located on the sides of the Orbiter are equipped with provisions for securing the panels with close-out strips and threaded fasteners. Concepts for attaching the close-out panels include special bolts covered with thermal protection system (TPS) plugs. Several of the concepts for special bolts will allow on-orbit removal of the bolts and TPS plugs to allow access to the Orbiter structures for attachment of special handholds and workstation supports (Figure 6.12).

Three concepts being considered by NASA (mid-1974) for securing the ground support access panels are shown in Figure 6.13. The concepts on the left and right would allow on-orbit removal of the fasteners and TPS plugs. The center concept would require removal of the entire panel and may not be a feasible EVA operation.

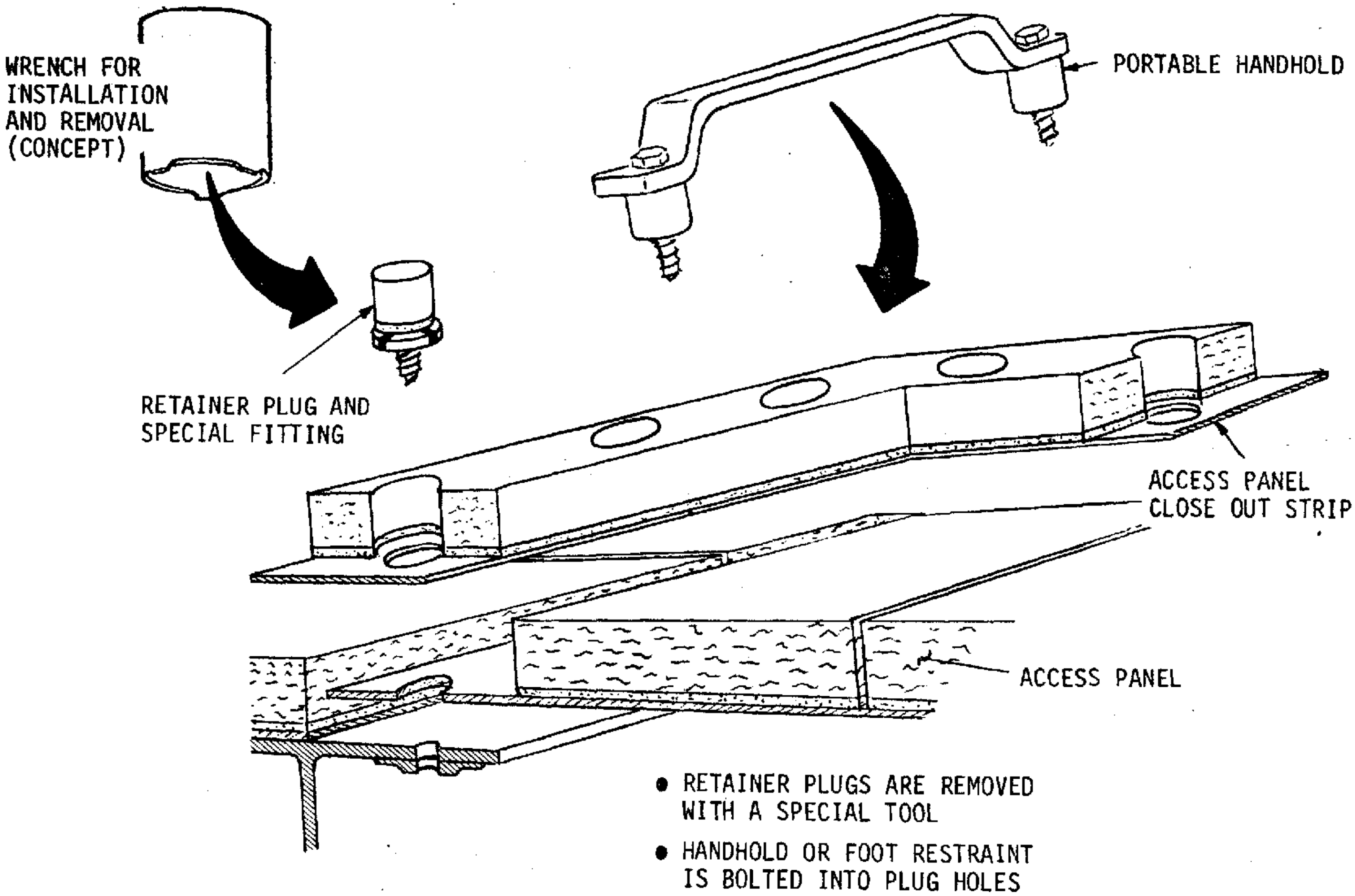
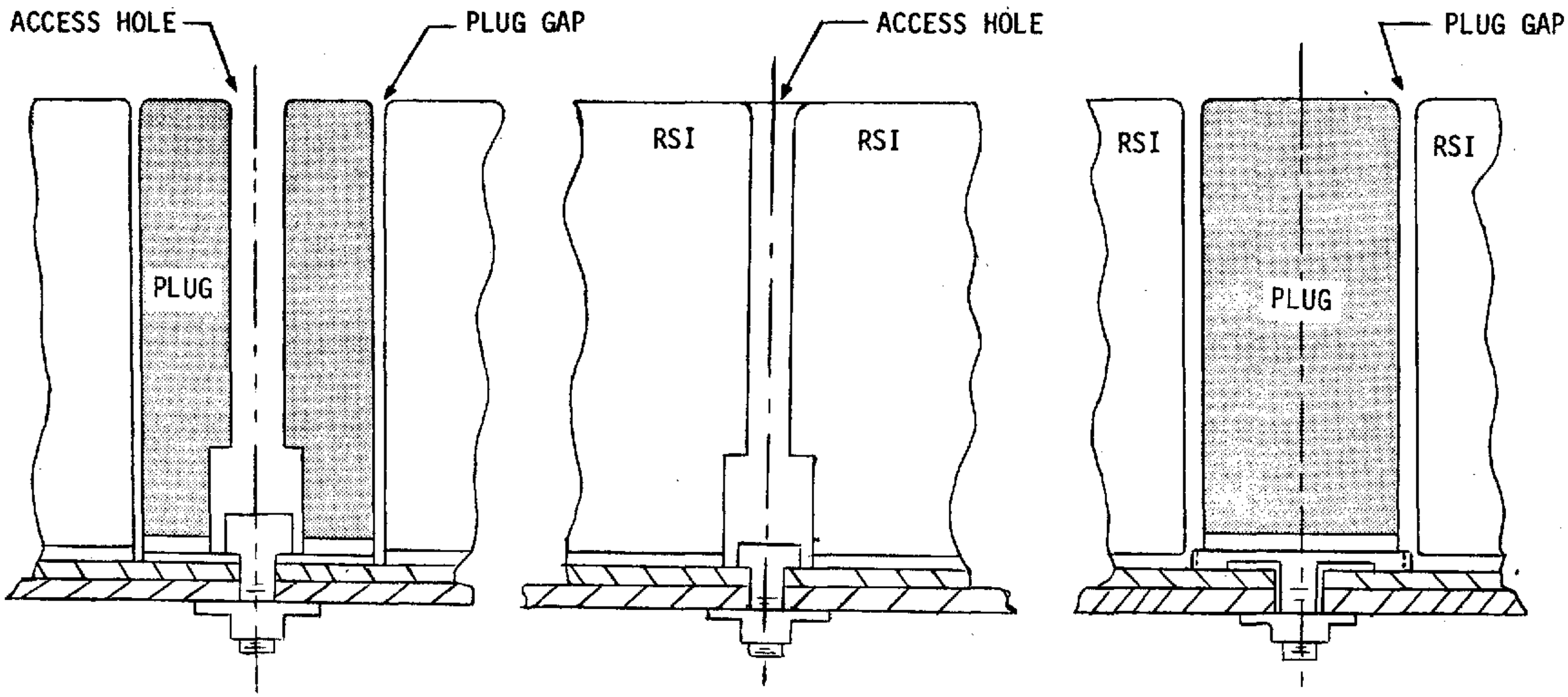


FIGURE 6.12: EVA Equipment Attachment to Vehicle--Orbiter Access Panels



CAPTIVE BOLT WITH REMOVABLE PLUG　　CAPTIVE BOLT--NO PLUG　　BOLT INTEGRAL WITH REMOVABLE PLUG (REQUIRES SPECIAL TOOL)

NOTE: Fastener concept to be evaluated by NASA

FIGURE 6.13: Candidate Orbiter Access Panel Fasteners

REFERENCES AND BIBLIOGRAPHY

REFERENCES

1. NASA: Summary of Gemini Extravehicular Activity, NASA-SP-149, Washington, D. C., 1967.
2. NASA: Gemini Summary Conference, NASA-SP-138, Washington, D. C., 1967.

BIBLIOGRAPHY

- NASA: Johnson Space Center Briefing on Shuttle Docking, EVA and Rescue Systems, LA 12-14-73, presented to NASA Headquarters, December 20, 1973.
- NASA: Space Shuttle System Payload Accommodations, Level II Program Definition and Requirements, JSC 07700, Volume XIV, Revision C, July 3, 1974.
- Martin Marietta Corporation: Shuttle Remote Manned Systems Requirements Analysis, Final Report, MCR-73-337, Contract NAS 8-29904, Volumes I, II and III, February 1974.
- NASA: Payload Descriptions, Volume II, Sortie Payloads, SSPD Document (no reference numbers), October 1973.
- NASA: Summarized NASA/ESRO Payload Descriptions, Sortie Payloads, SSPD Document (no reference numbers), October 1973.
- NASA: Payload Descriptions, Volume I, Automated Payloads, SSPD Document (no reference numbers), October 1973.
- NASA: Summarized NASA Payload Descriptions, Automated Payloads, SSPD Document (no reference numbers), October 1973.
- NASA: Payload Descriptions, Volume I, Automated Payloads, Level B Data, SSPD Document (no reference numbers), July 1974.
- NASA: Summarized NASA Payload Descriptions, Automated Payloads, Level A Data, SSPD Document (no reference numbers), July 1974.
- NASA: Payload Descriptions, Volume II, Sortie Payloads, Level B Data, SSPD Document (no reference numbers), July 1974.

BIBLIOGRAPHY (continued)

- NASA: Summarized NASA Payload Descriptions, Sortie Payloads, Level A Data, SSPD Document (no reference numbers), July 1974.
- ERNO-VFW-FOKKER: Spacelab Payload Accommodation Handbook, Intermediate Issue (Revision A), April 1974.
- ERNO-VFW-FOKKER: Proposal for the Spacelab, Design and Development Contract to ESRO/ESTEC, RFP AO/600, April 16, 1974.
- ERNO-VFW-FOKKER: Proposal Baseline Briefing Manual, Kick-off Meeting Phase C/D (no reference numbers), June 24-28, 1974.
- NASA: Final Report on the Space Shuttle Payload Planning Working Groups, Volumes I through X, Goddard Space Flight Center (no reference numbers), May 1973.
- Hamilton Standard: Space Shuttle EVA Contamination Study, Presentation to NASA-MSC (no reference numbers), February 20, 1973.
- Martin Marietta Corporation: Preliminary Design of an Atmospheric Science Facility, Final Report, MCR-72-322, Contract NAS 9-12255, December 1972.
- MBB: Earth Resources Payload for the Spacelab, European User Requirements, Presentation Material (no reference numbers).
- NASA: Large Space Telescope Phase A Final Report, Volumes I through V, NASA TMX-64726, Marshall Space Flight Center, December 15, 1972.
- ITEK Optical Systems Division: LST Phase A Study, Volume III - Design Analysis and Trade Studies, Final Report, ITEK 72-8209-2, Contract NAS 8-27948, January 8, 1973.
- Rockwell International: Shuttle Orbiter Horizontal Flight Configuration Failure Mode Effects Analysis and Critical Items List, Electrical Power Distribution and Control Subsystem, Contract NAS 9-14000, IRD No. RA-267T, WBS No. 1.2.5.2, SD74-SH-0070, January 7, 1974.
- Brown, N. E. Applications of EVA Guidelines and Design Criteria, Volumes I, II and III, Final Report, Contract No. NAS 9-12997, April 1973.
- Brown, N. E., T. R. Dashner, and B. C. Hayes. Extravehicular Activities Guidelines and Design Criteria, NASA-CR-2160, January 1973.
- Essex Corporation: Study of Roles of Remote Manipulator Systems and EVA for Shuttle Mission Support, Volume I, Contract No. NAS 9-13710, October 1974.